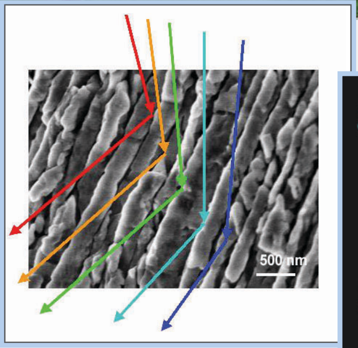
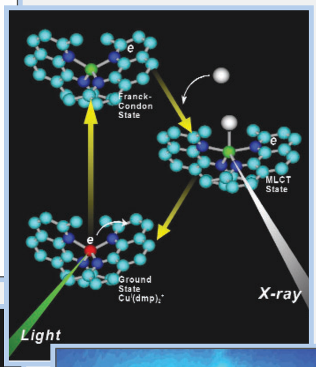
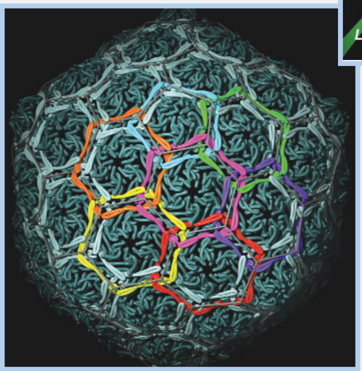
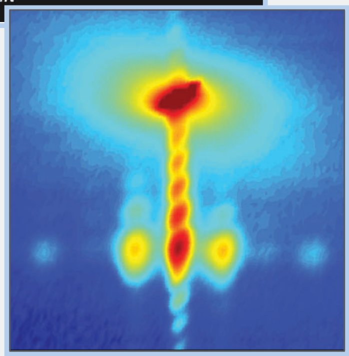
# The Advanced Photon Source

## Five-Year Vision for 2004-2008



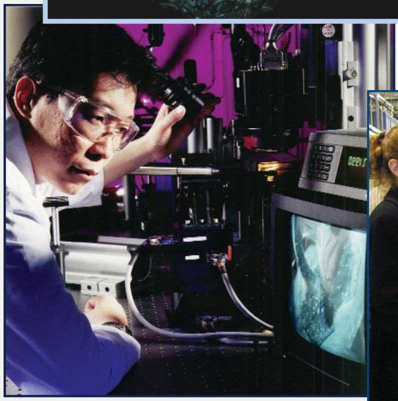





Prepared for

**The University of Chicago Review Committee for the Advanced Photon Source**

**September 17-19, 2003**

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# Table of Contents

# Executive Summary

This document describes the key successes, challenges, and plans for the Advanced Photon Source (APS) at Argonne National Laboratory (ANL) as the facility enters fiscal year (FY) 2004. This third-generation synchrotron x-ray source is the brightest of its kind in the Western Hemisphere. The APS has proven to be a highly reliable source of brilliant x-ray beams for an ever-growing user population that now numbers approximately 5,000. At the time this document was written, 43 of the possible 68 APS beam ports have been instrumented, and significant changes are occurring in the user programs and in operation of the facility. The changes were prompted by the maturing of the facility, new management, and valuable input from the U.S. Department of Energy (DOE) Basic Energy Sciences (BES) review of the facility held in October of 2001. Shortly thereafter, J. Murray Gibson was appointed the second Argonne National Laboratory Associate Laboratory Director with responsibility for the APS.

These changes and growth opportunities position us for even greater impact in the next five years of facility operation.

## Notable Successes:

The storage ring now operates at over 97% reliability.

The electron-beam emittance has been reduced by more than a factor of 2 since 1997.

Storage ring top-up mode of operation is an unqualified success and is being considered for use by light sources around the world, because it offers to users enhanced stability and improved performance.

Users of the APS facility have to date published over 2,000 scientific papers.

## Recent Changes:

Beginning in late 2002, the APS, for the first time, operated a fully centralized general-user (GU) program designed to improve access to the facility.

The APS has allocated increased resources to user support and related activities and has strengthened support and oversight responsibility for user experiment safety.

## Future Challenges:

We must continue to increase user access to the facility while retaining strong external partnerships.

The facility must take more responsibility for the operation of beamlines of interest to DOE-BES.

The facility must provide more support to all user sectors so that beamline scientists are free to focus on outstanding scientific productivity.

The facility is developing dedicated beamlines (both turn-key and state-of-the-art) offering high-performance, well-supported operations.

We must continue to improve the accelerator performance, especially beam stability, and to produce insertion devices optimized for the scientific needs of individual dedicated sectors.

We must continue to develop state-of-the-art detectors, optics, and beamline automation.

We must attract, develop, and retain the highest quality workforce in such critical areas as accelerator science and technology, as well as in x-ray operations and research.

This document describes (with appropriate background) changes that have been made by the APS to address these current and future challenges. A hallmark of these changes is the increased involvement of the user community in setting our priorities.

This document is accompanied by the 20-year plan (Appendix A) for upgrade of the APS, which we presented to the Basic Energy Scientific Advisory Committee (BESAC) in February 2003, phases I and II of which cover the next ten years and were strongly supported by the BESAC review.

# APS Mission Statement and Goals

- The mission of the Advanced Photon Source (APS) is to deliver world-class science and technology by operating an outstanding synchrotron radiation research facility accessible to a broad spectrum of researchers.

- Goals:
  - Operate a highly reliable third-generation synchrotron x-ray radiation source;
  - Foster a productive environment for conducting research;
  - Enhance the capabilities available to users of the APS facility;
  - Assure the safety of the facility users and staff and the environment;
  - Maintain an organization that provides a rewarding environment that fosters professional growth; and
  - Optimize the scientific and technological contribution to the Department of Energy and society from research carried out at the APS.

# 1. Introduction

The APS is the only third-generation, hard x-ray synchrotron in the Americas. This national research facility, which is funded by DOE-BES, has been operating for user experimentation since 1996.

The facility is, by any measure, an outstanding success. The accelerator complex delivers x-ray beams to APS users at a reliability rate above 97%. The APS user community now numbers approximately 5,000 researchers and continues to grow. The number of journal articles authored by researchers using the APS continues to climb each year, and the science elucidated in those articles is having an impact in many areas of our society. It is management's responsibility to assure that the APS evolves both technologically and programmatically to meet the needs of our current and future users, who will bring synchrotron-technique science to new realms of scientific discovery.

In this document, we outline APS management's vision for the future of the facility over the next five years. We do this in the context of both our successes in past years and the challenges we face today. This document is a blueprint for an organization whose users will have an immense impact on science and technology. The document is less a vision of the science itself and more focused on the structure and process for enabling that science. In the next few years, we will be developing more specific scientific plans, in consort with our users, for new scientific directions at the APS (see section 12).

Strategic planning is an essential component in addressing our unique challenges and opportunities. We were strongly influenced by the first DOE peer review of the APS in its fully operational phase, held in October 2001. An important first step in planning for the future was rearticulating our mission and major goals, which had not been changed since the facility construction phase. The two key elements of our mission can be cryptically labeled as *science* and *accessibility*. Our impact will be measured by the science carried out by our users. Clearly, we want to broaden and deepen our user community and strengthen our scientific review process in order to increase accessibility to the facility and expand our scientific horizons. Toward this end, concrete actions have been taken, such as the appointment of our new Scientific Advisory Committee (SAC) and the implementation of Internet-based tools for speeding researcher access. We also continually evaluate the budget that supports our mission goals, to ensure that the appropriate balance is maintained between facility and user support. And we continue to explore new avenues for communication with our users, such as the first APS-User Strategic Planning Meeting in Fontana, Wisconsin, in April 2002, and the APS/User Operations Meetings that are held every month, bringing together resident scientists and APS staff.

All of these factors, but especially the natural evolution of the APS and its users, have resulted in significant changes that we believe will foster development of our user community and the production of outstanding science.

The three APS divisions (reduced from the four that were in place in October 2001) reflect the components of our mission. This organizational consolidation allowed for reduction of duplication and improved efficiency. The high-level organization chart is shown in Fig. 1.

The Accelerator Systems Division (ASD) sees to the technical aspects of the accelerator and provides matrixed engineering and technical support across all of APS. The interactions between ASD, other APS divisions, and users have been expanded by the reorganization of April 2002.

The APS Operations Division (AOD) is responsible for all aspects of facility operation, from the machine control room and diagnostics, to user support and administration.

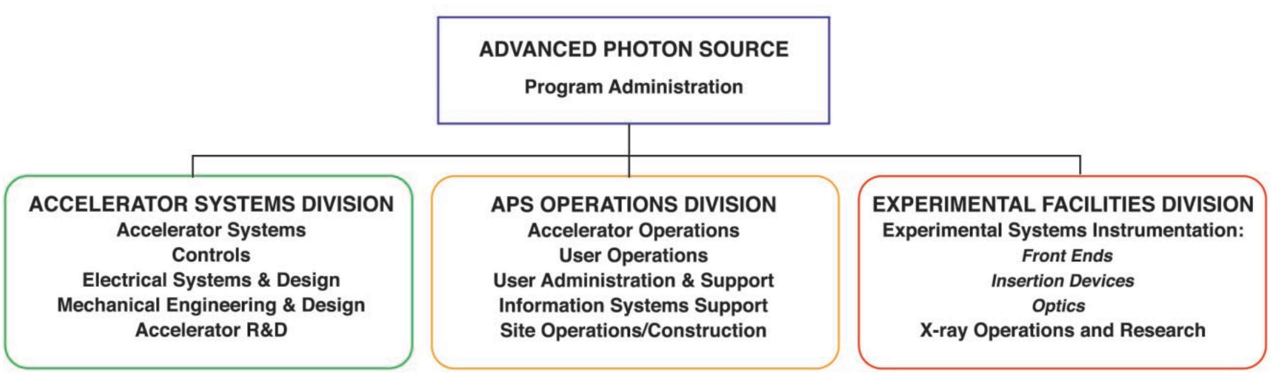



*Fig. 1. High-level organization chart of the APS.*

The Experimental Facilities Division (XFD), which contains the insertion device (ID), front-end, and optics research and development groups, is also the home of X-ray Operations and Research (XOR), which is responsible for all facility beamlines and beamline research. Details on the missions of each of these organizations can be found on our web pages at www.aps.anl.gov.

This document is not arranged strictly by organization, but according to function or issue. One of the goals of APS management has been to increase the interaction and interdependency of the APS divisions, providing a sharper focus on mission goals and increasing overall efficiency.

To date, users of the APS have published more than 2,000 peer-reviewed scientific papers, and over 130 graduate students have completed their theses based on work they did at the APS. In addition to user-science publications, over 1,500 other published papers have resulted from R&D innovations (mostly carried out by APS staff), in such areas as accelerator physics, mechanical and radio-frequency (rf) engineering, controls systems, IDs, optics, and other beamline instrumentation. Highlights from all research can be found in a number of APS-produced publications, including *Forefront* and *APS Research*. Most recently, we have issued a new-format annual report, *APS Science 2002 – The Annual Report of The Advanced Photon Source*, which is a comprehensive look back at the achievements of our staff and users during 2002. Our web site provides access to a constant stream of up-to-date research highlights. Figures 2 through 7 show demographic information about our users and their scientific and engineering impact.

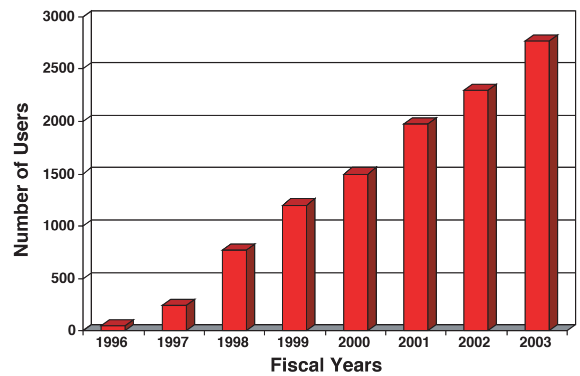



*Fig. 5. APS unique users, by fiscal year.*

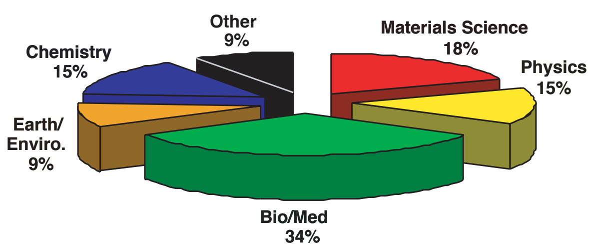



*Fig. 2. APS user demographics, by scientific discipline.*

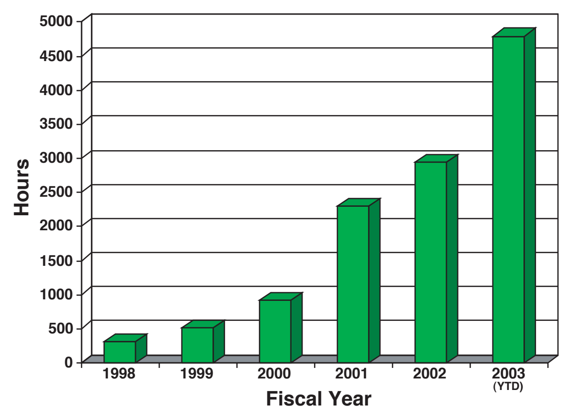



*Fig. 6. Hours of APS proprietary beam time, by fiscal year.*

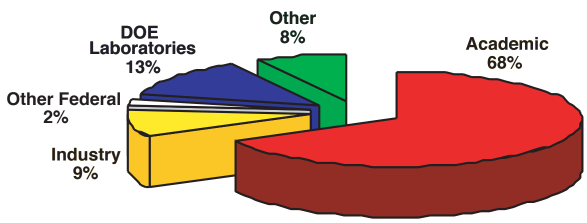



*Fig. 3. APS user demographics, by institution.*

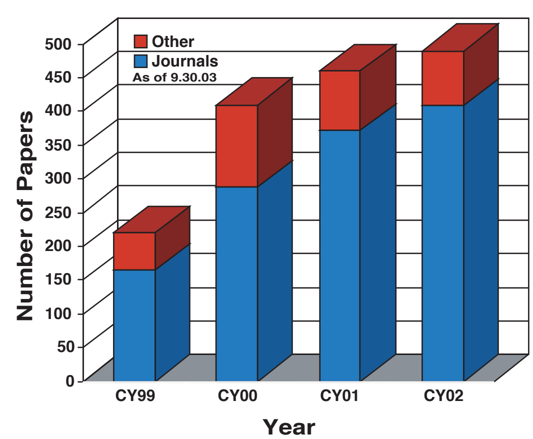



*Fig. 7. Number of APS user publications, by calendar year.*

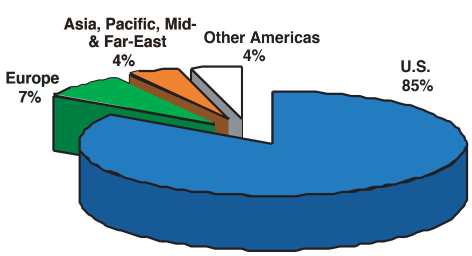



*Fig. 4. APS user demographics, by geographical distribution.*

## 2.1 APS Accelerator Operations

On March 26, 1995, the first x-ray beams from an APS bending magnet radiation source were delivered down a beamline, just a short time after the first subatomic particles made their initial orbit around the storage ring circumference. Five months later, the first ID beam traversed a beamline. Since then, the APS facility has steadily grown in both its capabilities and in its utilization by the synchrotron x-ray user community.

This consistent growth, as reflected in the number of unique users, experiments, and instrumented beam ports (either undergoing commissioning or running experiments), is shown in Table 1. The number of unique users is somewhat deceiving when viewed in the context of the large number of users visible on the floor, since many of the users return for multiple experiments (averaging between 2 and 3) during a given year. The beamline cumulative total is based on the date that each beamline received its first beam. Once the beamline receives its first beam and the radiation shielding integrity is confirmed, the beamline can begin commissioning activities and continue into operation.

*Table 1. Increase in APS users and instrumented beam ports.*

| FY | Unique Users | Experiments | Instrumented Beam Ports |
|---|---|---|---|
| 1995 | na | na | 2 |
| 1996 | 54 | 17 | 18 |
| 1997 | 243 | 119 | 24 |
| 1998 | 769 | 593 | 31 |
| 1999 | 1202 | 984 | 34 |
| 2000 | 1499 | 1224 | 36 |
| 2001 | 1976 | 1463 | 37 |
| 2002 | 2299 | 1704 | 41 |
| 2003 | 2767 | 2174 | 43 |

From the beginning of APS operations, accelerator-operation priorities have focused on two areas: availability improvements and performance enhancements. Prior to start of operations in 1996, the metrics for availability were established. The annual APS *availability* goal for delivery of user beam is 95% of scheduled time. Achieving high availability is critical in ensuring that experimental time is maximized. The annual *reliability* goal for the mean time between faults (MTBF), due to unintentional beam loss, was set at less than one fault every 50 hours. Maintaining high reliability is critical in ensuring that interruptions to experiments, even of short duration, are minimized. Beginning in FY 1997, detailed statistics have been collected. The history of APS accelerator performance is shown in Table 2.

*Table 2. APS accelerator performance.*

| FY | Scheduled User Hours | X-ray Availability (h) | X-ray Availability (%) | Faults | MTBF (h) |
|---|---|---|---|---|---|
| 1997 | 3140.8 | 2449.8 | 78.00 | 381 | 6.4 |
| 1998 | 4465.8 | 4163.3 | 93.23 | 124 | 33.6 |
| 1999 | 5053.6 | 4767.6 | 94.34 | 176 | 27.1 |
| 2000 | 5047.2 | 4723.8 | 93.59 | 160 | 29.5 |
| 2001 | 5000.3 | 4788.8 | 95.77 | 188 | 25.5 |
| 2002 | 4999.0 | 4855.6 | 97.13 | 147 | 33.0 |
| 2003 | 4912.0* | 4772.6 | 97.16 | 107 | 44.6 |
| TOTAL | 32,618.7 | 30,521.5 | | | |

*A shift in the start of the fall down-period resulted in a one-time loss of scheduled user hours in FY 2003.

Fiscal year 1997, while considered an operational year (*i.e.*, after Critical Decision 4), was actually a period of commissioning in that the facility was integrating engineered systems into the operational requirements for users. The goal of 5,000 scheduled hours of user beam was not in place in FY 1997 and FY 1998 because of the significant amount of work needed for ID, front end, and beamline installation. As Table 2 shows, availability has consistently improved. In the history of the APS, only one major downtime incident (>24 h) has occurred.

The APS has faced greater challenges in extending the MTBF. This number is even more important than availability to most users. Many engineered systems have been improved to address identified failure modes and we have been aggressive in implementing accelerator system enhancements, which have had a direct positive impact on the performance of user beamlines. Two of these enhancements, the implementation of real-time orbit control and the implementation of the top-up method of storage ring fills (both discussed later), were done at the cost of short-term increased faults.

## 2.2 Reliability and Availability Improvements

During early operation of the APS, the majority of interruptions to the delivery of beam came from two sources: rf trips and power-supply trips. Many improvements have been made to these complex systems since then. Operations in 1997 were plagued by nuisance trips from the storage ring rf high-voltage power-supply protection circuits. By the beginning of FY 1998, this problem was largely solved and was the primary reason for the significant increase in MTBF between FY 1997 and FY 1998. The ASD Radio Frequency Group has continued to address other problems in the storage ring rf system. In 2000, redundant hot spares were provided for all storage ring and booster rf systems, with a fast switch-over system. This redundancy has helped to reduce the mean time to recovery from a fault. In 2002, an rf test stand was completed, which enables the testing of new designs for cavity components and the conditioning of components (*e.g.*, tuners and couplers) destined for operation. These upgrades will improve reliability during the first few weeks of a run after work has been done on storage ring rf cavities.

The injector system has also improved considerably. Top-up operation places greater strain on injector hardware because of the constant operational demands of beam delivery every two minutes. A major availability initiative over the next few years will be to eliminate dependence on the positron accumulator ring (PAR). This small ring was installed to provide the option of using positrons in the storage ring because there were concerns about ion trapping of electrons. These concerns proved unfounded, and today the APS operates routinely with electrons and with the positron-production target removed. However, the PAR is still needed to capture sufficient charge from the linac and longitudinally manipulate it into a distribution that can be cleanly captured in a single booster bucket. Several techniques for operating without the PAR are being considered. The leading candidate is the addition of a lower-harmonic rf system in the booster. Direct injection from the linac into multiple buckets of the booster has been achieved. While not satisfying the ideal operational needs of users, this injection method does provide backup in case of future PAR downtime.

Several elements of the accelerator system have been in place for more than a decade and are in need of replacement or systematic refurbishment. Examples are vacuum pumps, vacuum-pump controllers, controls-system components, diagnostics components, and storage ring cooling water hoses.

The majority of our effort over the next five years will be to maintain the high user-beam availability that has now been achieved. Engineering solutions for a number of reliability issues identified to date have been proposed. These improvements will be carried out as the budget allows. Examples include improving storage ring magnet power supplies, upgrading linac klystrons to more-robust 45-MW tubes, redesigning the storage ring high-voltage power supply for the rf systems, and completing the spares inventory. Increased capacity and redundancy for the APS cooling system will be pursued, and we are providing for better immunity against power bumps – often the cause of beam loss. Long-range plans for maintenance and upgrades are developed in conjunction with APS annual budget planning. We regularly seek user input on the need for enhancements, through the Operations Directorate, the Partner User Council (PUC), and the Technical Working Group.

## 2.3 Schedule Development

The annual operating schedule has evolved in concert with user needs and facility capabilities. The early schedules for FY 1997 and FY 1998 included five to six user runs separated by an equal number of maintenance periods. These high numbers were driven by the need to accommodate the installation of beamline front-end components. However, each user run requires a preceding accelerator start-up period, which reduces the amount of time available to users. As beamline front-end construction slowed in FY 2000 and FY 2001, the number of maintenance periods, and thus the number of user running periods, was reduced to four. During FY 2002, a transition to three user periods was made, but this transition required the scheduling of four maintenance periods for that year. The schedule transition was completed in FY 2003. It consists of three operating and three maintenance periods. The three user running periods are October-December, February-April, and June-August. The end date of the summer run was recently moved to better accommodate the vacation schedules of our users and to make the three runs approximately equal in duration. This schedule is planned as a template for future years. It may be re-evaluated in 5-10 years once the pace of installation of new IDs and front ends slows.

A long-standing feature of the current operating schedule is the incorporation of periods for machine studies and/or maintenance interspersed during the user run. On alternate weeks, either an 8-hour or 48-hour period is scheduled. The flexibility of these periods allows adequate time for executing repairs that impact storage ring performance, replacing IDs, and making minor repairs to the beamline front ends without delaying repairs until the next scheduled maintenance period. This feature is even more important given the current long user running periods. We have consulted users concerning the use of weekdays or weekends for these regular interruptions, but it is clear that as many resident users prefer weekends as do those preferring weekdays. For the facility, the use of weekday periods is considerably less expensive.

## 2.4 Operating Modes

From the start of APS operations, only operating modes capable of supporting at least 100 mA of storage ring current have been used and a “single-bunch” mode has not been available. As a result, those user groups that require a single burst of x-rays rely on other methods, such as high-speed photon shutters and/or gated detectors. However, all attempts were made to provide a standard storage ring filling pattern that would allow for a majority of the timing experiments being considered.

The standard filling pattern currently consists of 24 bunches, equally spaced around the circumference of the machine. This pattern provides 150-nsec “dark time” between the x-ray pulses. For more stringent timing requirements, a hybrid operating mode includes either a single or a triple bunch centered over two-thirds of the ring circumference, with 56 bunches occupying the remainder. The single bunch is used where time resolution is critical, at the expense of beam current (the current is limited to ~5 mA in a single bunch), and the triple bunch emphasizes current (~15 mA in three contiguous buckets) at the expense of timing resolution. The hybrid operating mode is used during approximately 10% of the scheduled user beam time. We have recently introduced a 324 “multibunch” operating mode, which increases the lifetime and allows low-emittance operation during periods of non-top-up operation. In the near future, we intend to do a detailed review (in conjunction with the SAC) of the user science that requires timing structure in the beam to aid in developing the most scientifically productive future operating modes.

## 2.5 Accelerator Performance Enhancements to Date

Since 1996, five major accelerator enhancements have been implemented. These are:

### *2.5.1 Beam Stability Improvements*

Beam position stability is of utmost importance to the users of synchrotron light. The original APS specification called for storage ring beam drift and jitter to cover no more than 10% of the phase space area of the particle beam or less than 5% in any transverse phase space dimension (position or angle). Recent improvements to the storage ring, such as a reduction of the coupling (the ratio of vertical to horizontal emittance) from the original specification of 10% to the present 1%, and a reduction in the overall emittance by a factor of two, have made meeting this criterion even more challenging today. Slow (2-Hz to 0.016-Hz) orbit control through the use of rf beam position monitors (BPMs) was implemented in 1996. Real-time (2-Hz to 30-Hz) feedback and a dedicated high-speed data link were introduced in the summer of 1997. These changes brought the beam motion down to 8 μm rms in the horizontal plane and 4 μm rms in the vertical. Subsequent improvements to the dynamics of the feedback systems and reductions in the sources of beam motion have brought the motion to approximately 1 μm rms in both planes.

Concurrent with attempts to improve beam stability by using the rf BPMs has been the development and use of x-ray BPMs (XBPMs) in the feedback system, which has been a major effort involving many APS groups. To obtain useful XBPM data from ID beamlines, the unwanted x-rays produced by magnetic elements collinear with the ID must be eliminated. The APS developed a novel method of displacing the storage ring lattice so that only small correcting magnets at the ends of the IDs are collinear with the ID and any x-rays produced by these elements are correlated with the beam position in the ID. Displacing the storage ring lattice to accomplish this has been time-consuming and is now three-quarters complete. This work will continue over the next several years. Meanwhile, improvements have been made to the XBPMs themselves and their associated electronics. It is now possible to incorporate XBPM data into the feedback algorithms, although full implementation will also be done over the next few years. Further improvements are expected in the dynamics of the feedback systems; feedforward is being used to reduce ID gap-dependent systematic errors. The goal for beam stability (5% of beam size, which currently corresponds to about a micron) is made constantly more challenging as the APS further reduces emittance. The most optimistic plans require beam stability at ~0.4 μm rms. In addition to improving electron beam stability, the APS staff is working on individual beamlines to address solutions for identifying and reducing sources of local beam motion.

### *2.5.2 Small-Gap Insertion Device Vacuum Chambers*

For those users requiring special IDs, the APS has built and installed several very-small-gap ID vacuum chambers (5 mm internal, 8 mm external). To reduce beam losses on the IDs installed at these locations and to allow for more efficient injection into the storage ring, the storage ring magnet configuration was redesigned to reduce the vertical beam size in the center of the ID straight section. This redesign was initially done only at locations of the small-gap chambers, but it has now been employed around the ring. Small-gap ID chambers introduce a significant electrical impedance (currents flowing in the wall of the chamber that ultimately limit the amount of charge in a single electron bunch) and therefore will only be used where the need exists. In addition, there is recent evidence of radiation damage to IDs on small-gap chambers (see section 3.2), which must be considered in future plans.

### *2.5.3 Top-Up Operation*

Users of synchrotron light sources, such as the APS, benefit greatly from increased x-ray beam brightness. Brightness is determined by the emittance of the electron beam (a measure of how densely the particles are packed in all dimensions of transverse phase space), the current circulating in the accelerator, and the properties of the magnetic fields transversely accelerating the electrons. The circulating beam has a lifetime determined by intrabeam scattering and collisions with residual gas particles. The lifetime suffers as the emittance is reduced because of intrabunch scattering effects. Thus, a trade-off has always existed between producing very bright beams and maintaining a stored current. Additionally, the effective emittance is influenced by beam movement, especially in machines with very small emittance. The stability of the photon beam is strongly associated with the decay of the stored beam and consequent thermal variations on machine and beamline components. The performance of diagnostics systems is also adversely affected by the decay of stored current.

Given these facts, lifetime improvement is clearly of great importance to the operation of synchrotron radiation light sources. The ultimate improvement, one that essentially gives infinite lifetime, is top-up operation (Fig. 8). This mode of operation involves a regular injection on top of a stored beam while beamline shutters are open.

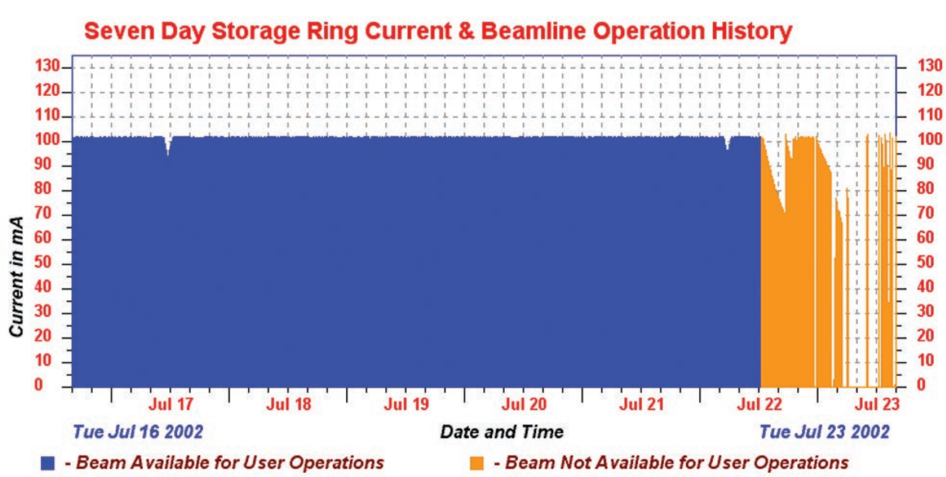



*Fig. 8. Actual APS storage ring top-up fill pattern. (Orange indicates scheduled machine studies period.)*

In principle, top-up operation is not fundamentally different from the "normal" process of injecting into an electron storage ring. During normal injection, beamline shutters are kept closed to ensure that none of the injected electrons will be extracted into an x-ray beamline, thereby creating personnel and equipment safety issues. During top-up operation, injection occurs with the shutters open. The key to demonstrating the safety of top-up was to ensure that, if a beam is stored in the accelerator, under no circumstances (including all combinations of known failure modes) could an injected beam exit through a photon beamline. This was demonstrated by APS scientists and engineers in 1997. The necessary interlocks, software, and procedures were then developed, and the APS now routinely operates in top-up mode. Since implementing top-up, the APS has been able to operate the storage ring with a lower emittance, increasing the brilliance by a factor of at least four. Additional enhancements to brilliance can also be considered that would otherwise be untenable without top-up. Furthermore, maintaining the current at the constant level of 100 mA provides a greater total x-ray flux than when the current is allowed to decay between refills. Perhaps most important to users is the increased stability of beamline optics that occurs with top-up, because the heat load is constant.

### *2.5.4. Reduction of Horizontal Emittance*

As noted above, top-up operation has allowed the APS to use modes of operation with lifetimes shorter than would be acceptable if top-up were not available. A reduction in emittance from the design value of 8.0 nm-rad to an emittance of 2.5 nm-rad has been in use since the first run of FY 2003. These reductions in emittance have been accomplished by changing power-supply currents within allowed operating ranges. The 2.5-nm-rad lattice, with 24 equally spaced bunches, is now considered the normal operating mode of the APS. The accelerator operates in top-up mode only 75% of the time, because of the need to retain flexibility in using the injector system for training, maintenance, and R&D. It was necessary to revert to the high-emittance mode in top-up to achieve a reasonable lifetime with 24 equally spaced bunches. Recently, the use of a 324-multibunch lattice has enabled running in non-top-up mode with the low-emittance lattice. This is now a standard non-top-up operation mode.

### *2.5.5 Dual Canted-Undulator Straight Section*

During the final run of FY 2003, the APS extracted two beams of hard x-rays from a single front end at sector 23, doubling the capacity of that source. The beams were produced by two undulators, each offset from collinear by 0.5 mrad, producing a 1-mrad separation. Steering magnets and beam-position monitors between the two undulators allow (limited) independent control of the two x-ray beams.

## 2.6 Accelerator Performance Enhancements: 2004-2008

APS staff have been planning further improvements in accelerator performance. Initially, this process involved meetings with accelerator physicists and representatives from the user community. At one of the first such meetings, held in January 2002, discussions centered on the possibility of increasing the APS storage ring current, but were broadened to consider other ways to increase beam brilliance. The ideas discussed in this and other meetings were then presented to the user community at the APS Strategic Planning Meeting in May 2002. Improvements were also proposed for IDs and beamline systems (discussed in sections 3.1 and 3.3). Task forces and additional workshops were set up to evaluate the range of APS enhancements and advise management on priorities. Consequently, accelerator studies will address and define issues that were raised during the initial meetings. For example, in many cases, the performance-enhancement cost cannot be known until physics specifications are better defined. Performance enhancements, including improvements in beam stability (discussed in section 3.5), are being undertaken. Other topics and options for implementation include the following:

### *2.6.1. Higher-Current Operation*

Presently, the APS storage ring is operated at 100 mA. The accelerator has been operated for studies at 200 mA, and it is believed that the ring could be run at 200 mA for operations with only minor changes. However, the front ends and many of the beamlines are not capable of operation at 200 mA. The APS staff is working with users to develop a plan for incremental increases in current up to 130 mA, and the storage ring has already run for one week of user time at 112 mA. An increase in current above the 130-mA level would have to come at the request of the user community and would involve costly upgrades. The APS is proposing to cover the cost of such upgrades in its long-range strategic plan. Also under development are improved designs for front ends to permit operation at higher currents. A full external review of these proposed design principles is anticipated by 2005.

### 2.6.2 Reduction of the Natural Emittance

Further reductions in storage ring emittance will require new magnets and power supplies. The APS will continue to explore design options and simulate the machine performance with these designs. Proposals will be presented as feasible designs are developed. Emittance decreases of greater than 30% are probably not possible without a significant alteration to the storage ring. The APS 20-year plan includes rebuilding the accelerator and injector complex for an order-of-magnitude decrease in emittance.

### 2.6.3 Longer Straight Sections

Longer straight sections allow the use of longer or additional IDs and produce higher brilliance. The storage ring was originally designed with this option in mind, but it would require significant modifications to the existing hardware (new magnets, power supplies, and vacuum chambers) to implement. This option will not work with very-small-gap IDs; in-vacuum IDs may be needed, and the potential radiation damage to in-vacuum magnets must be carefully assessed. This option could only be pursued at a few beamlines around the ring.

### 2.6.4 New and Novel Insertion Devices

New conceptual devices, such as superconducting, variable period, and pulsed electromagnetic devices, will present new challenges in (1) providing tight control of beam losses and (2) improving orbit control to compensate for changing magnetic field influences on the circulating particle beam. For more on this subject, see section 3.

### 2.6.5 Increased Single-Bunch Current Limit

The maximum current in a single bunch of electrons is limited by different criteria than those determining the maximum ring current. At present, the single-bunch limit is approximately 5.0 mA. Bunches with current greater than this become unstable because of electromagnetic interactions between the beam and the accelerator vacuum chamber. The APS will continue to identify and, where possible, eliminate the sources of these instabilities and explore the implementation of an active feedback device to damp this instability, thereby allowing larger single bunches for time-resolved experiments.

# 3. Delivering X-ray Beams: Insertion Devices and Front Ends

## 3.1 Insertion Device Research and Development

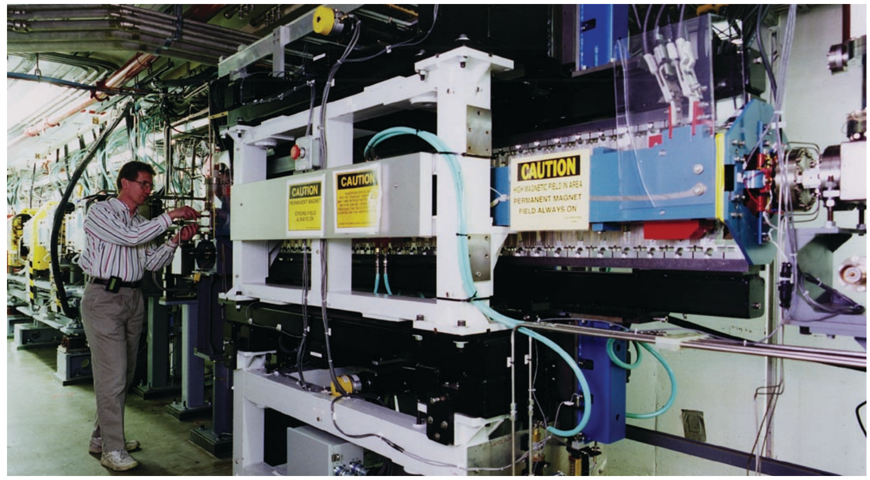
During initial operation of the APS, the standard ID for user beamlines has been the 3.3-cm-period Undulator A. It has proven to be a good general-purpose device, and making it a standard device enabled rapid procurement and a uniform algorithm for the magnetic tuning of IDs. As the APS matures, the opportunity exists to critically examine the appropriateness of future undulators to the research that will be carried out using them. Insertion devices can and will be customized for the few remaining new beamlines and for use as the second undulator in a straight section. Already, undulators with period lengths of 1.8, 2.7, and 5.5 cm have been installed to meet particular purposes. Recently, the dual canted-undulator configuration has been installed at sector 23 and another is in preparation for sector 24. For new canted-undulator beamlines, the APS is working closely with users to examine the advantages of an undulator with a period length of approximately 3.0 cm. Other period lengths will be developed as users request them. It is anticipated that the APS will develop a “stable” of IDs of various period lengths that collaborative access teams (CATs) can request for their beamline for a run or two.

As the APS evolves with more dedicated high-performance beamlines (see section 7), it is increasingly likely that specially tailored IDs will be installed permanently at many sectors. In this way, the scientific capabilities of each beamline will be maximized via optimized x-ray sources (phases I and II of the APS 20-year long-range plan).

Several groups of users have expressed a strong interest in a short-period, high-field undulator that has a first harmonic of approximately 25-30 keV. Design studies conducted at the APS suggest that the necessary high field strength can be achieved at a reasonable ID gap by using a superconducting planar undulator. Building such a device to meet the magnetic requirements and integrating it into the storage ring are major technological challenges. The APS has begun a feasibility study and plans to build a prototype in the near future. This activity will be coordinated with similar developments at other light sources.

Several experimental programs would benefit from a non-planar device. Two non-planar devices are currently installed at the APS: an elliptical multipole wiggler (Fig. 9) on sector 11 that can also be used as a planar wig-

*Fig. 9. The elliptical multipole wiggler installed in the APS storage ring lattice.*




gler; and a circularly polarized undulator on sector 4 that can deliver circularly polarized light of either helicity, or linearly polarized light with either vertical or horizontal polarization. These devices are either partly or fully electromagnetic, and the direction of the electromagnetic field can be switched (presently at a rate of up to 1 Hz) to select the required polarization state. Other types of undulators have been developed at different synchrotron radiation facilities around the world. For some devices, the main intent is to deliver particular polarizations of x-rays. For other devices, reduction of the on-axis power load by suppressing higher harmonics is most important. Often, both results are combined in the same device.

The APS is working with the user community to promote awareness of existing IDs and their properties and to bring attention to novel ID developments. A workshop on IDs was held in the fall of 2002 to present possible options to users. The APS will continue to work with users to help them select the ID characteristics that will best suit their experimental program. For example, the APS plans to develop a superconducting short-period undulator for the Inelastic X-ray Scattering (IXS) sector in order to increase the brilliance in the 20-25-MeV energy range. Additionally, a special device that provides circularly polarized radiation is being considered for the Nanoprobe sector associated with the Center for Nanoscale Materials (CNM) to reduce the on-axis brilliance heat load.

As described above, the APS is doing a detailed study of possible changes to the storage ring lattice that would lengthen several straight sections to as long as 10 m. This upgrade would allow for longer IDs and/or more undulators per sector.

### 3.2 Radiation Damage to Insertion Devices

The radiation dose to every ID on the APS storage ring is monitored. When top-up operation and a shorter-lifetime lattice in the storage ring became routine, the radiation dose level at the IDs in sector 3 reached previously unattained levels. As a result, the two undulators in that sector now routinely lose strength in their permanent magnets and must be removed and retuned each shutdown. Usually, simple retuning is sufficient to restore both the magnetic field quality and the harmonic intensity to the levels that would be achieved by a new ID. However, we recently discovered an ID on sector 3 that required more extensive reworking. Enough spare permanent magnet blocks were available to replace about one-eighth of the blocks in the undulator. Others of the remaining magnet blocks were rotated in place to move the damaged region away from the beam. The undulator was thus restored to near full strength. It was reinstalled before the end of the maintenance period so that experimenters never lost the use of the undulator during beam time.

A supply of spare magnets may not always be available. To mitigate similar problems in the future, a magnetizer has recently been purchased. Tests have found that the damaged magnets can be remagnetized to full strength.

The radiation dose in other sectors is typically ten or more times smaller than those in sector 3, so those undulators show no or very small changes in their magnetic field. Nonetheless, the occasional removal and rechecking of IDs during shutdowns will continue. The mechanism for the radiation damage continues to be studied. The XFD Magnetic Devices Group and ASD accelerator physicists are working to find effective ways to reduce the radiation dose and to minimize future damage to the ID magnets.

### 3.3 Future Front-End Development

As demand grows for increased brightness and flux, APS beamline front-end components must handle increased thermal loads, both in terms of total power and power density. Whereas APS front ends were initially designed to handle the power density of a single undulator in a straight section, several sectors are now planning for two undulators, and at least one sector is currently planning on three collinear undulators. Very-short-period superconducting undulators may also produce thermal loads substantially higher than those produced by existing IDs. Although the storage ring operating current is presently limited to 100 mA, recent tests have shown that operation to at least 130 mA is possible from a machine perspective, but the thermal load capacity of the installed front ends prevents any further increase. An experimental program in front-end high-heat-load engineering is required to accommodate multiple IDs, new types of IDs, or existing single undulators at higher storage ring currents. The XFD Experimental Facilities Engineering Group is engaged in this research. A program has been initiated to study the impact of thermal loading on the mechanical fatigue of front-end components, to assess the expected lifetime of installed components, and to design new components for the required loads and power densities. New component geometries, materials, and front-end configurations are being studied. An important aspect of the investigation will include experimentation with thermal loading on surfaces in the sector 4 Beamline Component Test Facility. In this facility, test pieces can be exposed to actual synchrotron x-ray beams and, by varying the incidence angle, the incident power density can exceed what is currently experienced in the storage ring. Instrumentation allows measurement of surface temperatures and cooling-wall temperatures. Thermal cycling tests and subsequent metallurgical examination will reveal the threshold for mechanical fatigue failure. Another component of the research is the development of methods for enhancing the average heat transfer coefficient that will allow higher peak power densities while providing robust performance in real-life conditions. By combining the experimental results with thermal and stress modeling, new designs will be developed that are capable of withstanding future x-ray thermal loads at the APS.

## 4. Partnerships for Beamlines at the APS

The APS has always relied heavily on external partners for the development and instrumentation of beamlines. Primary among these external partners are the CATs. A CAT builds and operates a sector and makes 25% of the sector beam time available to general users. The CATs at the APS (a current list is found in our 2002 annual report) have been very successful in that they:

- Function as outside intellectual drivers for the development of facility capabilities;
- Provide a strong connection with universities and other institutions; and
- Allow for the leveraging of funds.

In the 2001 DOE-BES review of the APS, it was noted that, while many CATs at the APS have been very successful, others have been less so. Among the problems identified were limited resources for operation, lack of motivation to bring in general users, and a tendency to needlessly duplicate capabilities available at other sectors. In addition, the reviewers pointed out that the APS could provide more assistance to the CATs to help them focus on their main scientific missions.

The APS is committed to the continued success of the CAT system, for the reasons listed above. However, we recognize our responsibility to deal with the problems that affect facility productivity. We need more flexibility in the nature of our partnerships. While a full-fledged CAT remains a viable option, we need to develop the ability to deal with groups that are not able or willing to take on responsibility for full operation. Toward this end, we must obtain the additional resources that will allow us to provide the operational support needed to bring these sectors to full potential. These resources will enable the facility to deal constructively with each of the problems identified and the users will benefit.

Changes in our policy must be taken in the context of a new policy from DOE-BES for the support of sectors that lie in their area of interest. The DOE-BES has stated their desire to transfer operational support of such sectors to the facility and has already done so in at least one case – the Basic Energy Sciences Synchrotron Radiation Research Center (BESSRC – sectors 11 and 12). This process is described in section 6.

The concept that there are, in reality, only two types of users (*general users*, researchers who apply for beam time through the APS peer-review proposal process; and *partner users*, individuals or groups who contribute to the facility or user community beyond simply performing good scientific research, as is typically the objective of a GU) emerged from extensive discussions within the facility and with other DOE light sources. The CATs are an important form of partner users, but we have introduced more flexibility into the concept. For example, a user may propose to develop an instrument in an end station, which takes some dedicated time to install and commission and will benefit the GU once the end station is in operation. Our new policies for general-user and partner-user access are given in Appendices B and C, respectively. While all user proposals are reviewed, a distinction for the partner-user proposals is that they are reviewed by the SAC.

Following implementation of the new access policies, the group formerly called the Research Directorate volunteered to reconstitute as the Partner User Council, which inherits all the functions of the previous Research Directorate, and which periodically meets to advise APS management. Each sector that has an external partner user has a representative on the PUC, and all CAT directors are members of the PUC. If a beamline has no external partners and is managed by the APS, then the appropriate beamline operations scientist can be an *ex officio* member of the PUC. The council also has been given an *ex officio* seat on the SAC, as is the case with the APS User Organization, to recognize the importance of communicating the perspective of our partner users.

## 5. X-ray Operations and Research

The mission of the former Synchrotron Radiation Instrumentation (SRI) CAT was to develop instrumentation and techniques that would be of value to the entire APS community. The SRI-CAT played a pivotal role in such developments as high-heat-load-optics, high-energy-resolution optics, phase retarders, zone plates, and choppers. The SRI-CAT also pioneered several techniques and helped develop user communities that have spawned new beamlines, including the IXS sector, the Nanoprobe sector, and the High-Energy X-ray Scattering sector proposal. The three current strategic beamlines — the x-ray microprobe beamline at sector 2, the inelastic scattering beamline at sector 3, and the polarization beamline at sector 4 — are all in full operation and in great demand by the synchrotron radiation community. In addition, the SRI-CAT has brought in hundreds of new users to the field of synchrotron radiation and has been a model for a successful CAT, demonstrating another important role for SRI-CAT as a crucible to lead the way for the future.

The organizational structure of the APS beamlines represented by the former SRI-CAT has been changed for several reasons:

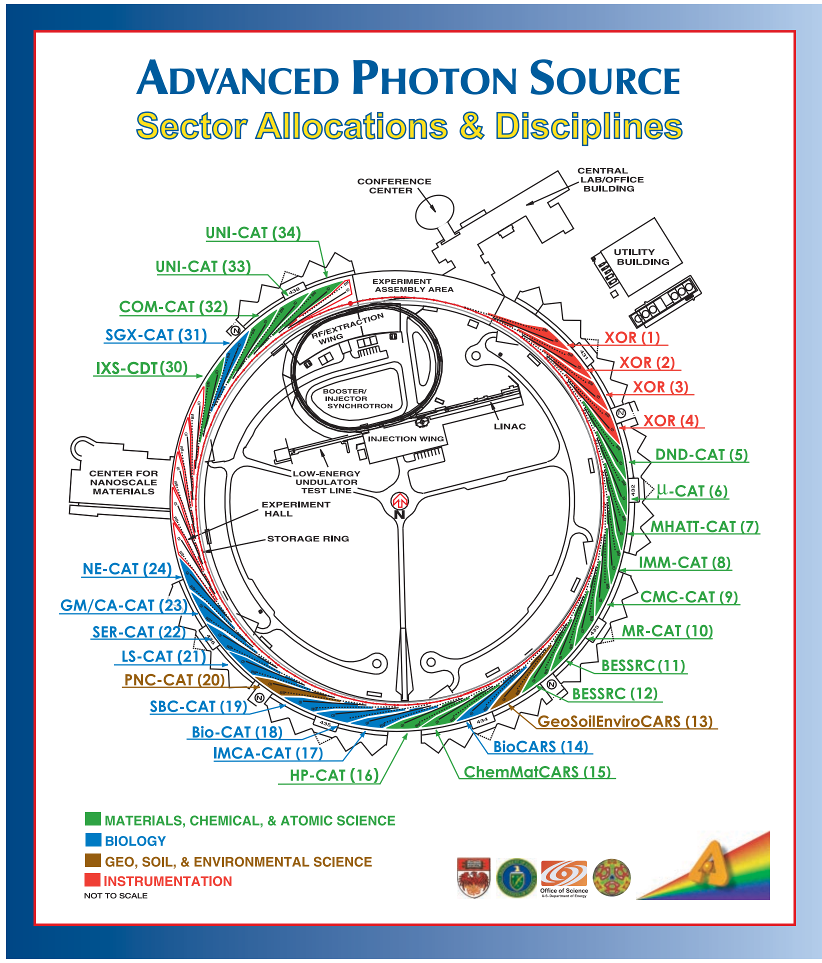
- To strengthen the GU program and make more time available for such users;
- To reflect the fact that the facility is taking expanded responsibility for operation of beamlines funded by BES;
- To recognize the need for greater flexibility in the mode of access to SRI-CAT beamlines, including increased and broader access for instrumentation development around the facility and the need to increase public access to sectors 1-4.

In response to these needs, the following changes were implemented:

- The SRI-CAT relinquished its status as a CAT effective January 1, 2003. The section of XFD that was home to SRI-CAT staff was renamed X-ray Operations and Research to reflect its dual roles. At the same time, XOR offered 50% of its beam time for GU competition.
- Of the beam time available on sectors 1-4, 80% was made available to GU proposals as of October 1, 2003. XOR scientists are free to submit general-user proposals and compete for time as would any other user. Review of all GU proposals is handled by independent proposal-review panels.
- XOR will continue to innovate instrumentation and push research frontiers through partner-user proposals, which will be reviewed by the SAC (see Appendix D). Under normal circumstances, XOR staff can recover, via partner-user proposals, up to 30% of the beam time, leaving at least 50% in all cases for GUs.
- XOR has provided full-time beamline operations scientists for each of the existing beamlines in sectors 1-4 and will be the future home for beamline operations scientists and other staff associated with BES sectors.
- XOR will manage operations of all beamlines for which it is responsible, independently from research and instrumentation development activities, with separate budget accounting and oversight by a specially designated manager within XOR.

# 6. Operations Support for BES Beamlines

The DOE-BES has stated that future operational support for CATs previously funded by BES will be gradually transferred to and provided by the APS, starting with the BESSRC sectors 11 and 12 discussed previously. At the beginning of FY 2002, approximately 10 operating sectors were receiving significant operational funds from DOE-BES. We anticipate that many of these sectors will, in future, become the responsibility of the APS. Currently, the APS partially supports three of these CATs, and has taken full responsibility for sectors 11 and 12 (BESSRC). Despite the challenges in retaining the strong partnerships embodied in these CATs, the new policy offers solutions to the problem of sustained operational support and allows the facility to develop, in conjunction with partners, the best suite of possible beamlines. All beamlines operated by the APS will ultimately become XOR sectors, and all staff and resources associated with these will be managed in the XOR structure. When a sector is in transition, we expect to accommodate users without serious disruption using a transition plan submitted through the partner-user process.




In FY 2002, sectors 7 (the Michigan-Howard-AT&T CAT), 8 (IBM-McGill-MIT CAT) and 20 (Pacific Northwest Consortium [PNC] CAT) sought APS support to replace or augment support formerly provided by DOE-BES. We engaged in dialogue with the management of each sector to determine the nature of that support, and undertook external reviews as appropriate. (In the future, we expect this aspect to be dealt with naturally by the SAC sector review panels.) In deciding on investments, we paid attention to the bigger facility picture and encouraged the development of appropriately specialized capabilities. For example, in the case of sector 7, we recognized the primary strength in time-resolved experiments. For sector 8, we identified the strength as photon correlation spectroscopy. For sector 20, we invested only in the bending magnet beamline, where the specialty is extended x-ray absorption fine structure (EXAFS). In each case, the sectors agreed to increase the share of available GU beam time to 50%. (For PNC in FY 2003, this applied only to the bending magnet beamline.) In each case, we provided approximately $100K support in FY 2002 and $600K support in FY 2003, typically including 2-3 staff members and other costs. As a result of our investment, each of these sectors now offers improved capabilities and staffing, and retains strong partnerships in a more openly competitive manner. These sectors are becoming integrated, from a management perspective, into XOR. We are gradually revising the XOR group structure to focus on common areas of science. For example, a new group focusing on time-resolved science includes staff from sectors 7, 8, and part of sector 1.

The APS and its users will benefit from this increased support for operation and expansion of XOR sectors. Using our partner-user process, we seek to retain strong scientific partners and provide better capabilities and support, but we intend to make decisions on such issues from a facility perspective. The SAC will play a pivotal role in this process. We appreciate that BES is committed to making this transition gradually over the next five years or so, allowing us to demonstrate the effectiveness of this new approach and minimize disruptions of research activities.

New beamlines receiving sector-construction funding from BES will, from the beginning, be incorporated into the new model. For example, the IXS sector has just signed a Memorandum of Understanding to begin construction in sector 30. Construction funds for this sector came from DOE-BES, the National Science Foundation, and partner institutions. These funds by themselves were inadequate to provide the equipment and effort costs needed to build a dedicated IXS sector with two instruments, as had been planned. Because this area of science is viewed by the APS and the SAC as very important, we are partnering to provide all the effort needed for construction and to develop specialized IDs to optimize performance. When the sector goes into operation, it will be managed by the APS as a conventional XOR sector. The group that raised funds for this sector has consolidated as a collaborative development team – the name reflecting the fact that the group functions like a CAT to build and commission a sector, but is not responsible for sector operations. Other new BES-funded beamlines will develop in a similar manner. The recent funding of a bending magnet powder-diffraction facility at sector 11 is an example of a turn-key beamline, which provides an equally important but somewhat complementary service to the dedicated experimental beamlines like IXS.

## 7. Beamlines – Facilitating the Growth of New Capabilities

There is a renewal of beamline construction activity at the APS following the large-scale construction of beamlines by the original group of CATs. It is fair to say that most, if not all, of these new beamlines can be labeled as second-generation beamlines (*i.e.*, beamlines that are more specialized in their mission and hence require unique/optimized IDs and special beamline components).

For instance, all of the new protein crystallography beamlines currently under construction at the APS are based on the canted-undulator concept (Fig. 10), which should double the productivity of each beamline where that configuration is employed. The undulators required for the canted arrangement are shorter (2.07-m) IDs than our standard 2.4-m undulators, and the front ends have been redesigned for this configuration to handle both the angular separation between the two beams and the increased total power that will be generated by the two IDs. The IXS beamline, the Nanoprobe beamline, and the proposed high-energy x-ray beamlines will all require IDs other than the standard Undulator A. These beamlines may need specially designed front ends as well.

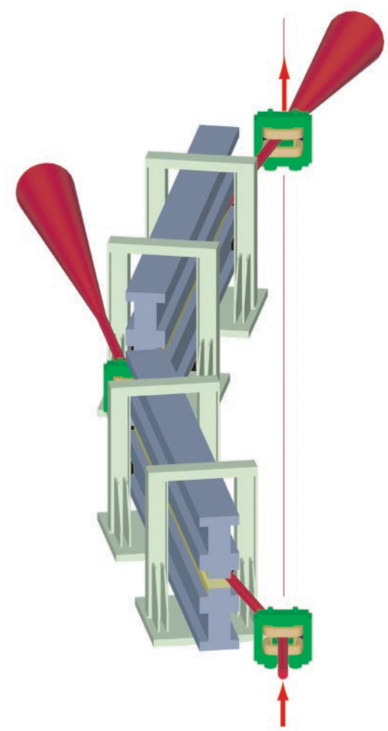


*Fig. 10. Diagram of the canted undulator configuration.*

Clearly, the APS will be heavily involved in developing both the IDs and the front-end components in a very collaborative way over the next several years, working one-on-one with the new beamline developers to ensure that these second-generation beamlines are truly at the cutting edge of current capabilities and that they will perform at expected levels.

The APS will also take the lead and work in close communication with all beamline developers in an attempt to standardize beamline control hardware and software. This approach will simplify troubleshooting of control/data acquisition systems by our centralized APS computer support organization. This same standardization approach will be phased in to the BES CATs, the operational support of which is provided by the APS, as outdated hardware and software is replaced with newer versions. These approaches will also lead to better economies, with centralized spares and replacements being maintained by the APS rather than by each individual CAT.

We believe that, over the span of the next five years, all open sectors will be assigned to programs and that the storage ring beam ports will have reached full capacity. However, by 2008, several of the original beamlines will be 10 years old (having been designed over 15 years ago!) and will need upgrades or, in some cases, to be completely replaced if the programmatic mission they once served is no longer a priority. Even if the mission of the beamline remains the same, improvements in beam brilliance will require upgrades of optical components if that beam brilliance is to be delivered to the sample. Other components, such as detectors, will also be inadequate. Maintaining the highest quality technical support of x-ray optical components and detectors (via the XFD Optics Fabrication and Metrology Group and detector pool) will be vital to keeping the APS competitive during the next five years.

Fig. 11. The home page of the APS web site. The “Beam Time” tab (circled in red) leads to access information for users.


## 8. Access by General Users

To facilitate the APS goal of fostering a productive and open environment for research, and to more effectively meet the needs of the rapidly growing synchrotron user community, we have developed a new policy and process for GU access (see Appendix B). Beginning with the first user run of calendar year 2003, the APS scheduled general-user beam time through a centralized electronic proposal submission, peer review, and allocation system. Proposals for over 35 beamlines that currently accept GUs are submitted through our central web portal (Fig. 11) at http://www.aps.anl.gov/user/beamtime/get_beam.html. For the first cycle, 320 GU requests for beam time were made. For cycle 2, this number rose to 350; for cycle 3, the number was 420 (not counting rapid-access requests, which come in throughout the run cycle). Approximately 60% of the requests in each cycle received beam time.

The policy underlying the central system was developed in close concert with users by a task force that was chaired by Dr. Lisa Keefe of the Industrial Macromolecular Crystallography Association CAT. The policy was formulated deliberatively, incorporating valuable experience from other facilities. Considerable effort was required to implement a fully electronic general-user proposal submission system. The process has worked extremely well, but a General User Program Advisory Committee the members of which draw from their practical experience, still advises the APS on potential improvements and/or enhancements as the program evolves.

In the fall of 2002, our web pages were substantially revised to enable general users with no APS experience to find the facility resources appropriate to their particular experiment. We now have on-line *techniques* and *beamline* directories. In the near future, we will optimize our resources to help novice users – for example, by providing a point of contact within APS for each technique, with whom a potential user can have discussions before submitting a proposal. In addition to improvements in our access system, we expect to facilitate an optimization of beamline capabilities that will benefit all users. We are exploring ideas related to turn-key beamlines for standard techniques, such as powder diffraction, EXAFS, and small-angle scattering, which will allow fast access for users and remove from many of the sectors the burden of support for these capabilities.


Fig. 12. Display prepared for the American Crystallographic Association 2003 meeting.

# 9. Enhancing User Productivity via Administrative and Technical Support

Technical; administrative; and environment, safety, and health (ES&H) support from the APS continues to grow in order to keep pace with the increasing size of the APS user community. The APS Operations Division is providing upgraded levels of support in each of these areas, as well as facilitating user and beamline-management access to technical support from the Accelerator Systems and Experimental Facilities divisions.

## 9.1 Administrative Support

The number of users traveling to the APS continues to steadily increase, and we hope that this number will double in the next five years. The APS will ensure that the User Office (UO) has adequate resources to meet the administrative needs of the user community. Users at the new Argonne CNM will also be supported by the UO. In addition, the registration process for all DOE-BES user facilities at Argonne will be centralized in order to streamline access. This system is being developed by the APS and will be administered by the UO.

The UO also manages the web-based, general-user program described in section 8. A general-user outreach program has been initiated and is being conducted cooperatively by APS staff and users. This effort began with the preparation and staffing of exhibits at selected scientific meetings. The first of these exhibits (Fig. 12) focused on research opportunities in crystallography through the GU program and was presented at the American Crystallographic Association meeting in July 2003. At least a third of the more than 800 meeting attendees stopped at the APS booth to pick up materials, talk about research opportunities, and learn how to use the on-line proposal submission system. Planning for outreach at other meetings is under way.

## 9.2 Technical Support

### *9.2.1 Detector/Electronics Pool*

An APS detector pool has been established on the basis of input collected from the APS user community. Data on detector needs and types were collected via questionnaires, meetings, and one-on-one discussions with sector staff. Information is also being gathered to determine what type of staff skills in support of the detector pool would best serve the APS user community. We envision that over the next several years, common spare detectors, along with unique and/or high-cost detectors, will continue to be acquired. The APS is collaborating with other DOE synchrotron facilities on developing proposals for funding to support detector R&D. Additional staffing will be needed in this area to:

- Properly maintain the detector pool,
- Evaluate and test commercial detectors,
- Provide detector-related expertise to the users,
- Conduct appropriate detector development, and
- Serve as the APS contact point for other facilities when detector-related issues arise.

The APS management began funding these activities in FY 2003.

### *9.2.2 Computer Networking/Beamline Control Systems*

The APS currently provides and supports the high-level computing network infrastructure for all of its user facilities. Planning is under way to further raise the level and quality of beamline computing support offered by the APS.

Driven by the ever-increasing levels of required security measures, one area of support that will be bolstered is network/computer cybersecurity. The APS will expand its role from merely administering network security to assuming greater responsibility for network and computer administration.

In many cases, the network structure for a particular sector is in need of documentation, physical improvement, and upgrade to take advantage of the gigabit networking infrastructure at the high-level network provided to the sectors by the APS. To meet these needs, only a limited number of operating-system platforms will be supported. As sectors, in particular BES-based groups, upgrade their beamline control systems, they will be encouraged to move toward one of the supported platforms.

Migrating to fewer platforms will make troubleshooting much more efficient (lessons learned from one beamline can be directly applied to others), permit the APS to establish a centralized spares system (eliminating the need for each sector to maintain spares), and facilitate the use of shared detectors and associated software.

Computer obsolescence typically occurs every 2 to 4 years. If adequate funding is available, the consolidation to a few operating systems and control solutions can be completed within the next five years. A task force will be assembled to advise APS management on what additional computer/controls/data-acquisition support should be considered. The task force will include members of the APS staff and resident beamline scientists.

Remote monitoring and/or control of beamlines will undoubtedly be another area that will require APS resources over the next few years. Several beamlines (both facility- and CAT-operated) have begun to explore the possibilities of having real-time, remote monitoring of data generated by the beamline and the demand for this capability will surely grow. The APS computer staff will need to work closely with the user community to provide high-speed, secure connections between the APS and the user's home institution to make this exciting new possibility a reality.

### 9.2.3 Optics Fabrication and Metrology

X-ray optics will continue to be an important area of support the APS can provide to the user community. The APS, with XOR staff taking a leading role, will continue to develop improved x-ray optical components (phase retarders, compound refractive lenses, etc.) with a particular focus on pushing the state of the art in hard-x-ray zone plates and being a source of such zone plates for the APS community. Although the importance of high-heat-load optics has diminished, activity in this area will be continued at a low level so that progress can be made toward handling higher power loads from longer IDs and/or higher currents.


*The Experimental Facilities Division X-ray Optics Metrology Laboratory in the APS experiment hall.*

Single-crystal fabrication will remain a mainstay of the optics fabrication team. Improvements in quality control will be a primary focus for this team in the next several years, along with advances in the surface finish of diffractive optics for phase-front preservation of coherent beams, an area of growing importance and interest to the research community.

The APS coating facility will have an expanding role in the field of x-ray optics, not only in the production of mirror coating and multilayers, but also in the final figuring of aspherical mirror components. One of the ongoing projects relates to the development of elliptically shaped Kirkpatrick-Baez (K-B) microfocusing mirrors using differential deposition techniques. Final figuring of mirrors through differential deposition can have an enormous impact in the field of microprobes over the next five years, pushing the focusing capabilities of K-B mirrors from the current level of slightly less than a micron to tens of nanometers. This increased focusing capability will require improved control over all three coating dimensions, which will be an important undertaking for the deposition facility over the next 3 to 5 years.

It is well known in the optics fabrication industry that only when improved measurement techniques are developed can systematic advances in the quality of optics be made. Maintaining the metrology program at its world-class level calls for continual upgrades in instrumentation in order to measure mirrors with ever-increasing accuracy and keep up the improved figures that differential deposition techniques will provide. Such techniques as differential deposition will likely push the measurement accuracy far below the limits of the current APS long-trace profiler. Therefore, over the next several years, a number of steps will be considered to increase instrument performance.

### 9.2.4 Mechanical, Vacuum, Survey, and Electrical Systems

The APS has already taken steps to improve user support in the areas of survey and alignment, mechanical engineering, vacuum engineering, and electrical systems. Accelerator Systems Division personnel will provide a significant portion of this support. These services will be organized and managed in a matrixed fashion to support both the accelerator systems and user community. A more formal and transparent mechanism for handling support requests from all sectors will be developed. In addition, this mechanism will allow APS management to better track sector support and to improve planning for the increased support requirements.

### 9.2.5 Additional User Technical Support

In anticipation of the continued development of new beamlines and a growing research community, AOD is committed to expanding technical support for experimenters and for the groups that manage the beamlines. The APS will continue to have floor coordinators on duty during all times that user beam is scheduled and to support beamline operations. The floor coordinators provide day-to-day oversight of beamline activities and coordinate user service requests.

To complement support provided by the floor coordinators, a Beamline Technical Support Group (BTSG) has been established in AOD. This group will develop common facilities and services for all sectors for a more efficient use of resources. The group will work with users to identify the specific areas in which support can most effectively be provided to increase researcher productivity. The BTSG will be involved in activities such as operating, or providing access to, equipment pools and/or common laboratory facilities; maintaining critical components; repairing cryopumps and other equipment; and facilitating the delivery of APS technical support. We anticipate that these shared resources will provide for efficiencies of scale to the researchers and the beamlines.

Continued improvement of the infrastructure at the APS will be an emphasis for AOD. A typical example of this is the installation of emergency power for beamlines, through provision of a generator-based source of electrical power. This emergency power will reduce the impact of power losses by allowing for the orderly shutdown of beamlines and the preservation of beamline controls settings and experiment data. The priorities for future infrastructure upgrades will be developed in consultation with the APS user community.

## 10. Safety and Quality at the APS

Safety and quality continue to be of paramount importance at the APS. In the spirit of integrated safety management, the responsibility for managing safety at the beamlines will still lie in large part with the beamline scientists, because they are experts in both the equipment needed for and potential hazards of the samples to be studied. Nonetheless, the APS is significantly and continually raising the level of user safety assistance and oversight. A fully electronic, web-based experimental safety approval form process has been implemented. Every experiment at the APS requires such a form, which is approved by the APS (through AOD) and the beamline administration. The spokesperson for the experiment also signs to confirm that the description of experiment hazards is accurate and that work will be performed within the controls described. Authorization to proceed is only possible with APS approval. The APS approval is based on:

- Definition of experimental activities;
- Identification of hazards;
- Specification of hazard controls that either
  - reflect APS standard hazard-control protocols or
  - have been reviewed and approved by the APS; and
- Plans for verifying that accepted hazard controls are in place.

In addition to the benefit of added oversight, the new process helps users understand hazards and supports the beamline staff who previously administered the system on their own.

As the user community grows, there will be a need to increase the level of ES&H support required to handle safety-related user support. To meet this need, and to more effectively coordinate user safety support, a new group called the User ES&H Support Group has been created in AOD to focus on the user safety program. This group will be led by the User Safety Officer, a new position. The group will develop and administer the user safety program (including experiment safety review) and manage the AOD Health Physics Group. The personnel assigned to the User ES&H Support Group will have the experience required to formulate and implement practical and reliable hazard controls consistent with relevant regulations and policies. The APS has increased the presence of its safety personnel in user areas, heightening the users' safety consciousness and providing them with more immediate support. A recent Occupational Safety and Health Administration review of the APS, which covered both the facility and user areas, was extremely positive, as have been other safety reviews throughout the life of the facility.

The APS has increased its direct support of sectors by having trained APS personnel carry out some of the safety-related maintenance and inspection activities formerly done by beamline personnel. This initiative puts the APS in a better position to detect potential problems and intervene when problems are discovered, while still preserving each sector's responsibility, accountability, and sense of ownership for safety. Concentrating support for user safety will allow us to build on our past strengths and prepare for the future.

Over the next few years, the APS will undertake a major effort to develop an electronic document management (EDM) system. The EDM system will help in the maintenance and oversight of critical components, and will improve the quality and reliability of APS systems. In the years 2002-2003, APS staff, with user help, developed guidelines for such an EDM system, which must incorporate drawings, memoranda, databases, and other critical documents. Introduction and use of EDM will follow a graded approach. Similar considerations apply to the development of APS project assessment and project management tools. Although these were used during the facility construction phase, a graded retention of these tools is needed for the foreseeable future.

Recent events have provided important lessons on the need for clear internal-review procedures and approval of modifications to critical components. We will incorporate all procedures for beamline and front-end critical components into our *Conduct of Operations* document, which in the past governed only the accelerator side. We have appointed a Critical Components, Front Ends, and Beamlines Manager, with overall responsibility for beamline and front-end critical components, consistent with the approach we use in overseeing work on the accelerator.

## 11. APS Scientific Advisory Committee

The APS Scientific Advisory Committee (Fig. 13) met for the first time in January 2003. The 16 members of this committee bring both depth and breadth to the review of scientific activities at the APS. Both the APS User's Organization and the PUC have *ex officio* representation on the SAC. Coincident with the establishment of the SAC, we began a new process of sector review, which is described in detail in the SAC policy (Appendix D) and the Partner User Access Policy (Appendix C). In our new sector-review process, a special sector review panel (SRP) established for each sector consists of at least six scientists versed in the science of the sector. Each SRP is chaired by a SAC member (the current membership of the SAC can be found in Appendix E). A stand-alone, one-day review by an SRP occurs at least once every three years for each APS sector. Results are shared with sector management and sent to the SAC, which makes recommendations to APS management. This process has been applied to nine sectors as of October 2003. The process combines the needed depth with the breadth of overall SAC review and we are confident that this will serve APS well in the future.

*Fig. 13. The first APS Scientific Advisory Committee. Left to right, standing: Wayne Hendrickson, James Norris, Paul Bertsch. Joachim Stöhr, John Helliwell, Peter Ingram, Pierre Wiltzius, William Bassett, Paul Zschack, Paul Peercy, Gerhard Materlik. Seated, left to right; Kathleen Taylor, Hermann Grunder (Director, Argonne National Laboratory), Michael Rowe (SAC Chair), J. Murray Gibson, and Denis McWhan. Not pictured: Howard Birnbaum.*

The SAC is also involved in other important activities. These include an annual cross-cutting review of science at the APS; in January 2004, the review subject will be "Science with Microbeams." In addition, the SAC is actively involved in reviewing and developing APS policy.

## 12. New Scientific Directions for the APS

The SAC has commissioned a study on new scientific directions for the APS. The study is co-chaired by Dr. Gopal Shenoy (XFD) and Dr. Sunil Sinha (University of California, San Diego). At the time of this writing, there are only four uncommitted ID beam ports at the APS. Several proposals have already come forward for their use. It is important to think carefully about the assignment of these final sectors, and so we have prompted a set of workshops and requested user input on areas of science in which the APS could have an impact. We chose to make the study broad; it will look at incremental and revolutionary areas. We hope that many exciting ideas will emerge for experiments with existing beamlines, for beamline improvements, and for completely new beamlines and sectors. We aim to have a set of outstanding proposals for the remaining sectors in accordance with our long-range plan to finish and upgrade beamlines in the next few years.

An important science frontier for the APS is nanoscience. The APS is a partner in the Argonne CNM. The center will consist of a building, funded by the State of Illinois and attached to the APS, with equipment and operating expenses funded by the DOE. Among the equipment will be the dedicated Nanoprobe beamline, which will aim for the highest spatial resolution hard x-ray microscopy. There will also be a suite of synthesis, processing, and other characterization equipment for nanoscience research. We anticipate that many users and beamlines at the APS will benefit from this new user facility.


*Artist's rendering of the Argonne Center for Nanoscale Materials, to be constructed at the APS.*

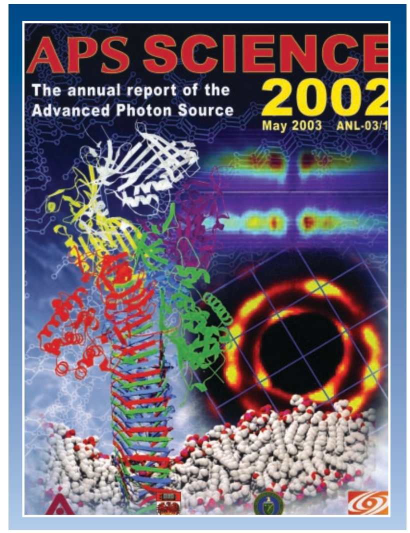
The APS is also collaborating on the Linac Coherent Light Source (LCLS), which will be one of the first x-ray lasers in the world. The APS is to produce the undulators, representing >20% of the total LCLS project cost. It is very beneficial for the APS to be associated with the LCLS and future fourth-generation sources, both from the user point of view and for the accelerator scientists and engineers whose expertise is very valuable to the LCLS as well as to the APS. To gain a glimpse of the potential experimental issues that may arise from using a short-pulse source (such as an x-ray free-electron laser), several APS staff members are participating in the Sub-Picosecond Photon Source project at the Stanford Linear Accelerator Center (SLAC). The APS has contributed a (currently unused) wiggler (with help from the BioCARS sector and The University of Chicago) that has been installed at the end of the SLAC inac for production of subpicosecond hard-x-ray pulses, and we are members of the scientific collaboration performing experiments with those pulses.

A new endeavor initiated by Dr. Kwang-Je Kim,of ASD, seeks to coordinate accelerator physics within Argonne and the local community. This is the CARA effort, for Coordination of Accelerator Research at Argonne, which is funded through the Laboratory Directed Research and Development program.

# 13. Publicity and Education

The APS must effectively inform, persuade, and educate as to the value derived by the scientific community, the DOE, and the American taxpayers from the accomplishments of this facility's users and staff. These communication efforts (otherwise known as "publicity" and "outreach") are centralized under APS Scientific Information Services (APS-SIS). Information about the APS is communicated in language that is appropriate to a variety of specific audiences. These are synchrotron x-ray users; potential users, and the broader community of scientists who are interested in important scientific advances; the public (*i.e.*, educators and students, the scientific and popular press, decision-makers, and funding agencies, especially DOE); and the staff of the APS. In addition to producing the materials listed below, APS-SIS is the point of contact between user institutions and the ANL Communications and Public Affairs (C&PA). In addition to press-related cooperative endeavors, SIS works with C&PA to match APS speakers with interested local audiences.

## 13.1 Publicity Materials




The new APS annual report (right), *APS Science*, contains highlights from published APS research results, reports from APS divisions and research groups, and operational and user statistics. It is produced once a year and distributed to all APS users and staff, others in the synchrotron x-ray and broader scientific communities, potential users, and funding agencies. The first issue was published in 2003.

Activity reports, which are recent results from the APS, are written by APS users and collected on CD-ROM, as well as posted on the APS web site (http://www.aps.anl.gov/aps/activity_reports/webars.html).

Individual research highlights are published in a wide-ranging array of 4-color, 1-page articles that cover the spectrum of APS science in a manner suitable for the general public. New materials are continually developed and produced. These articles are available in the atrium of the APS central lab/office building and in any quantity via a request to apsinfo@aps.anl.gov. In the near future, these highlights will be downloadable from the APS web site.

*The Source*, the APS employee newsletter, is distributed periodically in .pdf format. It serves as a vehicle for management communication with APS staff and resident users, news about developments and accomplishments at the facility, and news about personal and professional achievements by APS staff.

The APS-SIS is tasked with developing World Wide Web-based content that communicates information on the APS research programs and highlights. The SIS also maintains the web-based, publicly available, comprehensive database of scientific publications authored by APS users and staff (http://www.aps.anl.gov/aps/science-publications.html).

***The students and faculty of the 2003 National School on Neutron and X-ray Scattering, held at Argonne on August 10-24. The main purpose of the school is to educate graduate students attending U.S. universities on the utilization of major neutron and x-ray facilities.***

## 13.2 Education

The APS has always been a major supporter of the National School on Neutron and X-ray Scattering held annually at ANL since 1998. This highly oversubscribed school for graduate students provides not only tutorials in many aspects of neutron and x-ray scattering techniques but also hands-on experience performing experiments at both the APS and the Intense Pulsed Neutron Source. Other education-related initiatives include an APS poster distributed to 3,500 Midwest high school science teachersin conjunction with a highly successful contest that solicited from area students designs for hands-on exhibits demonstrating the scientific principles on which APS research is based.

# 14. Organizational Structure and Resources

The APS organization has been adapted to carry out an evolving mission, from the conceptual stage of the project through the design, construction, commissioning, and early operational phases, and now into its role as a world-class research facility. Figure 14 follows the evolution of the staffing profile from the major construction year, FY 1993, to the present. Fig. 15 shows the current staffing by area.

The two largest activity areas in Fig. 15, accelerator systems operation and maintenance, and APS support services, are further defined in Figs. 16 and 17.

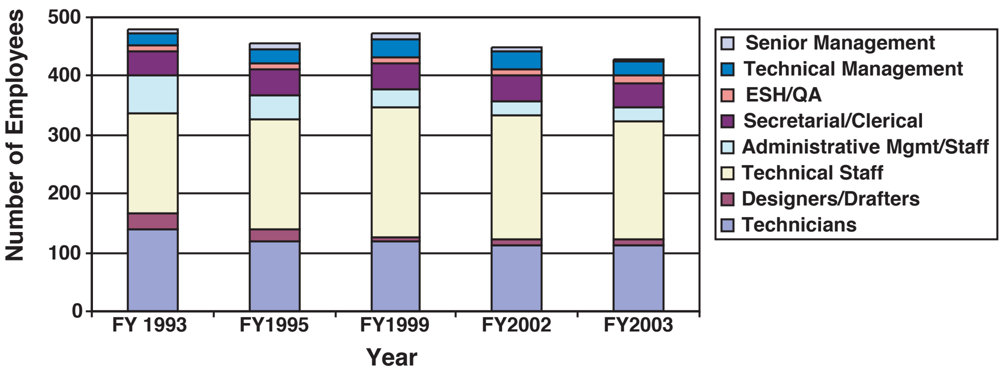



*Fig. 14. APS Project staffing, by function and fiscal year.*

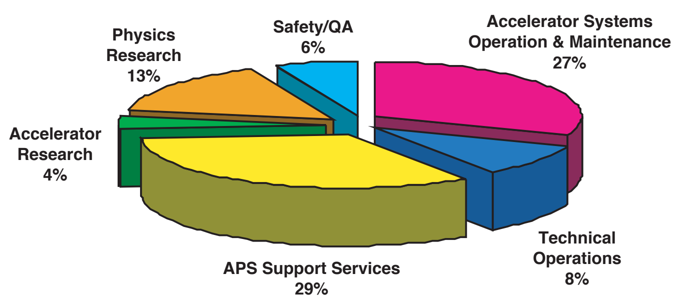



*Fig. 15. Current APS staff profile, by area.*

The reliability and availability of the APS accelerator systems are of paramount importance to our mission. More than 40% of the annual APS budget is devoted to reliability and availability, not only for machine operation and maintenance but also for developing improved operating techniques and system enhancements. Operation and maintenance of the accelerator systems account for 35% of the personnel resources and involve engineers, physicists, technicians, operators, and others ("Accelerator Systems Operation and Maintenance" and "Technical Operations" in Fig. 15).

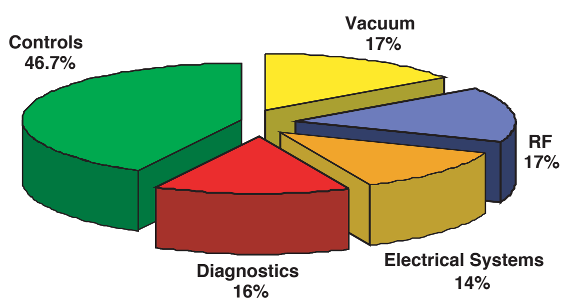



*Fig. 16. Distribution APS of staff assigned to accelerator systems operations and maintenance.*

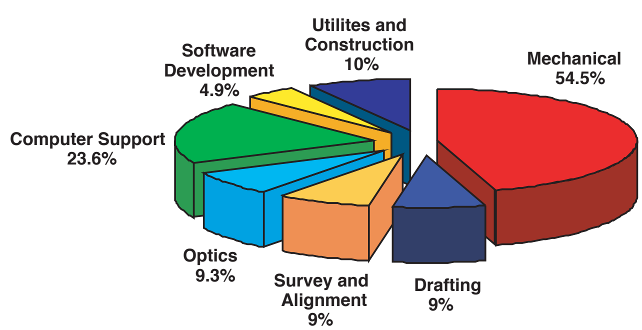



*Fig. 17. Distribution of APS staff assigned to support services.*

Activities associated with supporting the ongoing and new programs of the APS and its users are shown in Fig. 17. They range from engineering and construction, which provide users with assistance in developing and building their beamlines, to optics and software development to assist users in their scientific programs. Twenty-nine percent of APS staff resources are devoted to these support services.

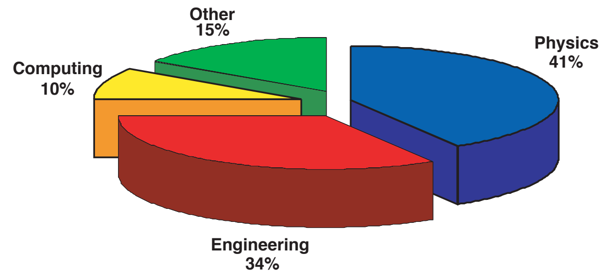



*Fig. 18. APS professional staff , by area of expertise.*

The APS staff comprises scientists and other professionals, technicians, draftspersons, administrative and clerical personnel, as well as students and others. In addition, ANL personnel assigned to the APS in support roles include utility operations, building maintenance, custodial services, rigging, library services, procurement, machine shop, and stock handling. The general makeup of the APS professional staff by discipline is shown in Fig. 18.

The major source of funding for the APS is the Scientific User Facilities Division of DOE-BES. The results of the APS internal review of the allocation of its funding resources relative to its mission goals is seen in Fig. 19, which show the spending of the FY 2003 budget by function, compared with FY 2001. Comparing these figures shows that ~9% of the resources have been moved from accelerator systems to the user side. The accelerator systems support cannot be further reduced to accommodate expected increase in user activities without risking adverse impact on the performance of the machine.

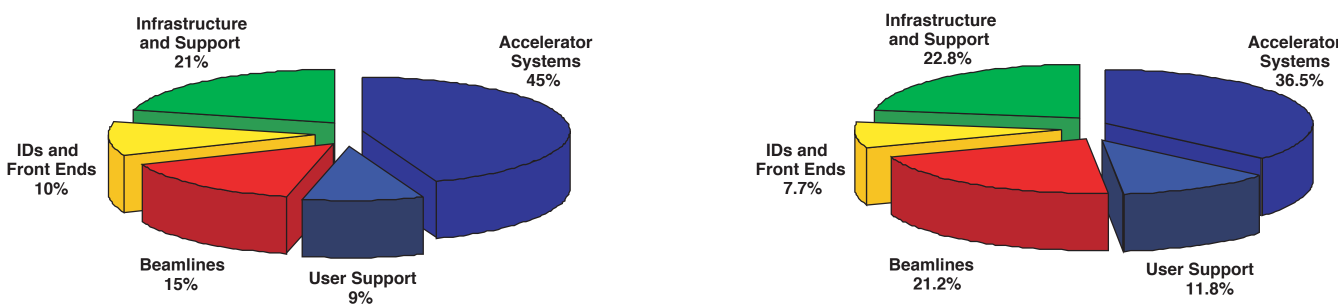



*Fig. 19. Comparison of APS spending, by function (left: FY 2001; right: FY 2003).*

## 15. Conclusion

The APS has made many changes aimed at enhancing the future success of our users. We have allocated additional support to user activities and streamlined our accelerator activities. We will continue to improve accelerator capabilities and optimize our beamlines and our x-ray sources for the best science.

Enhanced user support and capabilities will make the APS more accessible to an ever-growing user community. We will strive to retain strong external partners in our beamlines. By combining an appropriately centralized high level of support with strong partners and assuming continuing and growing support from the DOE, we can fulfill the ideal model of a user facility in the United States.

# Appendix A:

# Advanced Photon Source Upgrade Path – Defining the State of the Art: A 20-Year Roadmap

February 23, 2003

# Advanced Photon Source Upgrade Path – Defining the State of the Art: A 20-Year Roadmap

**February 23, 2003**

## Introduction

The Advanced Photon Source (APS) at Argonne National Laboratory (ANL) is the latest addition to the Department of Energy's (DOE's) suite of synchrotron radiation (SR) facilities. The APS is the only high-energy (7 GeV) 3rd-generation source in the U.S. Construction of the APS began in 1989, and the first x-ray beam generated by an insertion device (ID) was extracted in August 1995. Assignment of beam ports to programs is typically done by sectors (a sector is one ID port and one bending magnet [BM] port). Of the available 68 beam ports, 38 ports on 25 sectors at the APS have been built (25 ID ports and 13 BM ports). Three other sectors have been assigned to specific programs (with construction scheduled to begin soon), and 2 additional sector assignments are imminent, leaving only 4 sectors not yet committed.

Over the last several years, the growth of users has been rapid. In fiscal year 2002, the APS had over 4500 registered users on its records, of which approximately half participated in experiments during the year. Even a conservative growth estimate points toward an APS user community of 10,000 by 2013. To satisfy the commensurate growth in demand for beam time, the APS must start now to (1) develop the remaining available beam ports, (2) optimize the beamlines and instrumentation to provide the most effective use of this valuable national resource, and (3) develop procedures to facilitate easier access to the facility and beamlines.

The APS has an outstanding history of synchrotron radiation instrumentation innovation. The APS staff are internationally recognized leaders in the development of IDs and novel beamline designs, such as the canted-undulator scheme for providing more insertion device-based beamlines for a given number of straight sections in the storage ring that has been very popular with the macromolecular crystallography community. The APS is the only facility that operates routinely in top-up (constant current) mode and is at the forefront in the development of techniques for improved beam stability. Our highest priority is to maintain a leadership position in technological innovations related to synchrotron radiation sources and instrumentation with science driving these directions.

Over the next twenty years, new and exciting sources, namely energy recovery linacs (ERLs) and free-electron lasers (FELs) should, and undoubtedly will, be built in the U.S. These unique sources are not simple enhancements of 3rd-generation sources but rather are a new breed of sources with new properties and applications. And although some of the users of today's synchrotron radiation sources may be users of these new facilities, ERLs and FELs will not replace existing sources for a majority of the current researchers. Hence it is imperative that the APS remain at the cutting edge of 3rd-generation synchrotron radiation technology as the demand for 3rd-generation sources will not decrease in the next 20 years.

Innovations such as those mentioned above are precisely what will be required for the APS to continue the leadership role for defining the state-of-the-art in storage rings, insertion devices, and beamline technology. It is these strengths that will allow us to support the mission of the APS and DOE, namely to deliver world-class science and technology by operating an outstanding synchrotron radiation research facility accessible to a broad spectrum of researchers. And it is these strengths on which we base the guiding principles for future developments at the APS over the next 20 years. To reiterate:

- The need for 3rd-generation SR sources will not diminish in the next 20 years;
- In fact, it is likely that our user base will grow to well over 10,000 in the next ten years.
- A fourth-generation source should be constructed in the U.S., but it will not replace third-generation sources, which will continue to remain the centers of excellence for a majority of the light-source-based experiments in the foreseeable future.

Therefore, the APS must continually increase its capabilities and effectiveness with evolutionary improvements in accelerator performance, IDs, optics, beamline design, detectors, and the integration of robotics and automation. These advancements will define the state-of-the-art 3rd-generation x-ray sources. Our vision is for an upgrade path that will allow the APS to optimize the scientific and technological contribution to the DOE and society from research carried out at the APS is described in detail below.

# A 20-Year Upgrade Path

Our plan for upgrades over the next twenty years can be divided into four phases: Phase I involves completing beamline installations on the remainder of the storage ring and maximizing existing beamline operations; Phase II will focus on optimization of source characteristics; Phase III will center on developing the next generation user facility through improved efficiency and performance of beamlines, advanced detectors, robotics, and automation; and Phase IV will involve a major upgrade of the accelerator complex to develop a super photon ring. By necessity, these phases will overlap in time. In appreciation of the continued demand for beam time at 3rd-generation sources, our plan calls for only one extended shutdown over the next twenty years for the implementation of the new linac and storage ring in Phase IV. Overarching all phases of this plan is a proposal for a Center for X-ray Science and Technology to be organized in support of the science and engineering developments at the APS.

## Phase I – Maximizing Beamline Operations

### *Proposal and the Importance of the Science It Would Support:*

Given that the APS is not fully outfitted with beamlines on all available ports, clearly the focus of the first phase of a twenty-year plan for the APS will be on full utilization of the storage ring. We expect on the order of 10 new beamlines will begin construction over the next 8 years (2004-2012) corresponding to the 4 remaining unassigned sectors (2 beamlines per sector) and the building of several bending magnet beamlines. These are in addition to three sectors dedicated to macromolecular crystallography about to begin construction (funded by sources other than DOE) and the ID beamlines for two very exciting proposals that have been partially funded by DOE/BES for construction: the inelastic x-ray scattering (IXS) beamline and the nanoprobe beamline that will be associated with the Center for Nanoscale Materials (CNM). The average time from conception of a beamline to commissioning and start of user operations is approximately five years, and so we believe that the construction period for the remainder of the available sectors will continue through the next decade.

In parallel with new beamline construction, we must contend with the aging of existing beamlines. On several beamlines, ten years have already passed from their original design, and they will be in need of major refurbishments over the next decade. Major advancements in optics and instrumentation have taken place over those ten years, and many beamlines are no longer able to meet the ever-increasing technical requirements of the users and/or may no longer be at an optimal performance level. This is compounded by the fact that the present storage ring operating parameters are much better than the original specifications on which the beamline designs were based. Construction and refurbishment of some of the beamlines will be the responsibility of the APS in collaboration with partner users while for others the APS will be solely responsible. The proposed science for those beamlines will be the driver for new construction and upgrades. The APS will rely heavily on advice and guidance from its Scientific Advisory Committee (SAC) in determining what new beamlines will be built and/or upgraded.

We envision that future beamlines will fall into one of two major categories: those that are used for “routine data collection” that need to be turn-key in nature and those that will be optimized for “experiments”, *i.e.*, those that are cutting edge in nature where constant innovation and tweaking is necessary for scientific success. Small angle x-ray scattering (SAXS) is an ideal candidate for a user-friendly, turn-key beamline. SAXS is a convenient means of probing structural features in the range of nanometers to hundreds of nanometers in a wide variety of materials. Knowledge of the structure of a material is key to understanding its physical properties, its chemical reactivity, and/or its biological functionality. Both the chemistry and physics of modern materials demand that structural information be obtained in a routine fashion and with state-of-the-art precision. SAXS is a definitive tool for such studies. A user-friendly dedicated SAXS beamline would bring this state-of-the-art capability to the APS and would encourage the rapid growth of that user community. A second candidate for turn-key operation is microdiffraction with 1-5 micron spatial resolution. Although not “state-of-the-art” in terms of present day spatial resolution, a dedicated polychromatic microfocusing beamline would provide a unique approach to studying materials properties on a mesoscopic scale. Other techniques for turn-key operations include EXAFS, powder diffraction, and macromolecular crystallography. All these techniques are invaluable tools that can be applied to problems in a wide range of scientific fields from the life sciences to the physical sciences.

On the other hand, inelastic x-ray scattering is prime example of an "experiment," as it requires highly complex setups (high-resolution monochromators, secondary monochromators, backscattering analyzers) and typically has very low count rates and therefore requires extended beamtime. Inelastic x-ray scattering can offer insight into the dynamics of soft-matter systems (polymers, proteins. and membranes) and hard-matter systems (ion dynamics in solids, liquids and gases, and electron dynamics in strongly correlated systems). X-ray photon correlation spectroscopy (XPCS) is another example of an "experimental" technique. This technique yields the intermediate scattering function of the sample and is a tool that can be used to probe hard- and soft-condensed matter samples. Both small-angle and wide-angle geometries may be employed for the study of small-scale dynamics, including out-of-equilibrium systems. Today, XPCS experiments are signal limited and hence require special attention to, and the development of, novel beamline hardware. Because this technique is in a nascent stage of development, not only will hardware need to be developed, but also the data analysis needs to be developed and made available to users of such a beamline. Another candidate beamline for the "experiments" category is a dedicated facility for the study of materials under extreme conditions, such as pressure, temperature, and magnetic fields. Several beamlines already exist at the APS for high-pressure studies, and high-temperature capabilities are currently being developed. Dedicated low-temperature and high-magnetic-field capabilities do not yet exist and need to be added to the suite of sample environments that are permanently available on APS beamlines. Such beamlines will undoubtedly increase both the quality and quantity of the scientific output of the facility in a variety of fields including the study of magnetism, superconductivity, phase transitions, and lattice dynamics. We will also explore the possibility of a beamline dedicated to coherent imaging. This is a relatively new technique that is being developed at several places around the ring, but there currently exists no dedicated beamline for this exciting tool. A glimpse of the work that might be performed using coherent imaging was work on the breathing of insects that recently was highlighted on the cover of Science (January 24, 2003).

An important aspect of Phase I is the completion of the APS vacuum ultraviolet (VUV) FEL on the low-energy undulator test line (LEUTL) and an associated beamline, which is comparable in cost and scope to a new beamline on the storage ring. Continuation of this project permits important accelerator physics activities, such as gun development for 4th-generation sources, to proceed and will facilitate a new class of experiments to be performed at the APS. The APS VUV FEL has already achieved saturation in the range from the 660 nm to 130 nm and operates independently of the storage ring when the storage ring is running in non-top-up mode. Independence during top-up mode can be achieved through an "interleaving" concept where the linac is time-shared between storage ring injection and FEL operation. Currently the FEL is servicing a single scientific program–a VUV single-photon resonant ionization to threshold experiment for the detection of trace amounts of light-element isotopic abundance in stellar matter. If funds were available, a full user facility in this interesting wavelength range could be developed for utilization from a wider scientific community.

### *Readiness:*

The APS is already proceeding on many aspects of Phase I but on a limited basis due to resource constraints. We are contributing resources to new beamlines in the form of front ends and IDs through our operational funding. To fully support the operating cost of existing (and new) beamlines, the beamline operational staff must increase. We estimate that nearly 100 beamline scientists and support staff (some of which we have but many of which will be new hires) will be needed to optimally operate all the BES beamlines by the next decade and will require a 20% increase to the current APS operations budget to support the additional staff. We firmly believe that increased operational staff can have a significant impact on the scientific productivity of both existing beamlines and newly constructed lines. Construction could start on a laboratory office module (LOM) immediately since it would be a copy of the other LOMs.

### *Cost, Schedule, Scope, and Technical Management:*

Phase I should be started as soon as possible and will continue for at least 10 years from the start date. We estimate this phase to cost approximately $160M for completion of the ten new beamlines, refurbishing of approximately another ten, and completion of the final LOM associated with the new beamlines. The timeline and budget profile for Phase I can be found in Appendices A and B, respectively. We will seek some portion of the required funds from outside of direct APS funding through partnering agreements, as was successfully achieved for the initial construction with many of the Collaborative Access Teams (CATs). Beamline construction/refurbishing will be managed by APS staff, who have considerable experience in this area, in collaboration with partner users.

## Phase II – Optimizing Source Characteristics

### *Proposal and the Importance of the Science It Would Support:*

Given the current magnetic lattice of the APS storage ring, further reductions in the natural emittance (presently at about 2.6 nm-rad – almost a factor of 3 below the original design specification) will be incremental. Therefore, without a major reconstruction of the storage ring, significant increases in beam brilliance will have to come from the development of optimized IDs and/or increases in circulating beam current. Concomitant with new IDs and higher current, compatible front ends and optical components will also be required. In fact it is likely that all of the original front ends (FEs) will need replacing/upgrading to meet the thermal requirements of longer IDs and higher currents. The combination of optimized IDs, improved optics, and higher beam currents could result in improved brilliance on the sample by more than an order of magnitude over current conditions (*i.e.*, from a brilliance of a few times $10^{19}$ photon/sec-0.1% bw –$mm^2$-$mrad^2$ to a brilliance of almost $10^{21}$ in those same units).

Insertion device development will push towards shorter period devices for attaining higher energies (20 to 45 keV) with the first harmonic. We believe the most promising approach is with superconducting undulators. Increased brilliance at high photon energies (25 keV and above) will enhance the capabilities of the inelastic x-ray scattering program (the importance and impact of a high-quality inelastic x-ray scattering program has been stated previously) and provide an unequalled source of high-brilliance hard x-rays for high-energy elastic scattering. High-brilliance beams of hard x-rays can be readily focused to several microns today and submicron focusing will be possible in the future. A small focal spot size, in combination with the penetrating power of hard x-rays, is the perfect ingredient for a three-dimensional x-ray diffraction microscope. An important use of a 3-dimensional x-ray diffraction microscope is in the area of fundamental studies of polycrystalline materials. This is a unique tool for the study of stress partitioning between grains, stress distribution within grains, grain rotation, and grain growth. It gives access to properties of individual grains that are buried deep inside of bulk material and allows 3-dimensional mappings at the mesoscopic scale. Since it is nondestructive, it allows for the study of dynamics and pre- and post-processing states of specific regions within samples and can be done in situ. No other nondestructive method is available for obtaining this information with the resolution of the 3-dimensional x-ray diffraction microscope.

In addition to optimized IDs, we have begun a program to explore the possibility of increasing the length of straight sections in the storage ring for longer/multiple IDs to further improve beam brilliance. Initial results indicate that modifications of the storage ring lattice are possible to allow an increase from the present 5 m clear space for IDs to a 10 m clear space in a few places around the ring. Increased brilliance will be particularly important for photon-hungry experiments, such as inelastic scattering, high-resolution imaging, correlation spectroscopy, and time-resolved studies, all cutting edge techniques. Longer straight sections would also allow elliptically polarizing undulators optimized from 0.5 to 3 keV to be installed. These devices would have brilliances in excess of $110^{19}$ photon/sec-0.1% bw –$mm^2$-$mrad^2$ resulting in a world-class beamline for photoemission and a photoemission electron microscope (PEEM) with a few nanometer spatial resolution for the study of magnetic properties of materials. It is important to point out that although many associate high energy (particle beam) storage rings with the production of hard x-rays, 6-8 GeV is an ideal stored beam energy for the generation of elliptically polarized soft x-rays. This, combined with the inherent better stability of the higher energy beams, result in high energy storage rings having a considerable advantage in the generation of high quality polarized soft x-ray beams. The APS is the only high-energy 3rd-generation storage ring in the U.S. and is likely to remain so in the foreseeable future.

In addition to superconducting and polarizing undulators, solenoid-driven undulators will also be pursued. Solenoid-derived IDs allow for simultaneous variable-period/variable-field IDs (as compared to present-day fixed-period, variable-field devices) that could have applications in a host of scientific pursuits where “optimization” is required at several different energy ranges.

As stated earlier, although substantial reduction in the natural emittance is unlikely with the present lattice, the effective emittance delivered to the user can be improved by enhancements in beam stability. Continued focus on this effort must be maintained in addition to the enhancements described above. This would have a major impact on all brilliance-dependent experiments. In addition, because top-up is a highly desired mode by the user community, additional activities will also focus on reducing the size and duration of the perturbation of stored beam during the top-up process which will further enhance the quality of the user beam.

### *Readiness:*

As was the case with Phase I, the APS has in place active programs to enhance source properties. Work has already begun to explore the feasibility of short-period superconducting (SC) IDs for higher energies. Work has also commenced on looking at the feasibility of extending (doubling) the length of the straight sections at a few places in the storage ring. Initial indications are that this is a viable proposal with minimal impact on the operational parameters and performance of the storage ring. Conceptual design work has also begun on a new variable polarization undulator for soft x-ray production and on the solenoid-driven ID. This work could be accelerated significantly with an influx of additional funds. As with the case of beamlines, we will rely heavily on the SAC to provide us with advice on the prioritization of these efforts with the goal of optimizing scientific productivity of the facility.

### *Cost, Schedule, Scope, and Technical Management:*

We estimate that construction for Phase II would start in the third year of the 20-year plan and continue for approximately a decade (see Appendix A). The cost for replacement of front ends, IDs, and beamline components (optics, beam stops, etc.) for the oldest 25 sectors is approximately $4M per sector or about $100M total. (Note that not all beamlines would require new IDs, while others may require multiple IDs to meet the needs of their scientific program.) A budget profile for Phase II can be found in Appendix B. We have on the staff the expertise in engineering and beamline design to successfully manage and carry out this project.

## Phase III – Next-Generation User Facility

### *Proposal and the Importance of the Science It Would Support:*

To accommodate the estimated 10,000 researchers that will use the APS beamlines in ten years, the ease of access, beamline performance, and data collection speed must be improved. We envision that there is a large class of experiments that can be effectively performed via remote access if real-time communication of data, experimental conditions, and beamline control can be achieved. State-of-the-art detectors can also speed up the data collection process and make the facility more productive. Both these activities will require additional APS staff.

Automation and robotics for sample alignment have already been implemented on macromolecular crystallography beamlines at the APS and other facilities. We believe that automation, combined with improved detector readout capabilities, could easily double the throughput of crystal structure determination on the existing macromolecular beamlines at the APS. It seems that similar techniques could well be applied to physical science beamlines as well. For instance, the integration of automated sample changers into powder diffraction beamlines and small-angle-scattering beamlines seems to be a straightforward extension of the sample changers for macromolecular crystallography. But we should not stop there. Automated alignment of optical components and diffractometers could substantially increase scientific productivity particularly (but not exclusively) on the turn-key beamlines proposed in Phase I. It is therefore important to incorporate the concept of automation in those beamlines from the beginning of the design.

Significant improvements in throughput for nearly all experiments can be made through the use of better detectors. Today we have experimenters mapping grain orientations and stress in “real materials” with volumes of 104 cubic microns at one micron resolution. At a recent visit to the APS, after initial setup and alignment, the user needed a total of 54 hours to collect the data; 52 hours out of 54 went to reading out the detector–only about 4% of the beam time was used to record the data! This is one of many such examples. We simply must improve these situations, otherwise we are wasting a valuable national resource.

Another driver for automation is the ever-increasing demands of cutting-edge science. In all likelihood over the next ten years, the best science, of which nanoscience is a prime example, will require precision and control of samples and instrumentation that are simply beyond present capabilities (*e.g.*, the x-ray nanoprobe). Ever more demanding science will put yet higher demands on beam stability. At some point, the attainable stability of the beam from the storage ring may still not satisfy some portion of the user community, and we will rely on local feedback of optics, sample, and detector in a coordinated fashion to maintain the relative position of the x-rays on the sample. We therefore propose a major effort in the area of integrated feedback systems to stabilize beamlines to the same level that has been achieved in the storage ring by accelerator physicists.

We estimate that the implementation of automation/robotics will be an ongoing project commencing in 2010 and will be coupled in with the normally required beamline upgrades and improvements. Detector upgrades could start much earlier, but in some cases the necessary detectors will in all likelihood not be developed and operational on a shorter time scale. Detector developments, along with advances in optics and beamline control/data analysis, that are all important components of Phase III would be a major emphasis of work at the Center for X-ray Science and Technology.

### *Readiness:*

Synchrotron radiation facilities, including the APS, have only begun to explore the potential improvements that automation can bring, and more R&D is required before it can be routinely implemented in all beamlines. This year the APS has also allocated operations funds to nucleate a detector pool that will permit beamlines access to state-of-the-art detectors on an as-needed basis. However, to expand this concept to a larger number and/or more sophisticated detectors, additional resources will be required. To be ready to implement the next generation of detectors in 10 years, R&D in detector development must start in the next several years. Although it will take a few years to retrain or hire new staff to support these activities, we believe that we could be ready to begin outfitting beamlines with new detectors and automation on a regular basis in about 7 to 10 years.

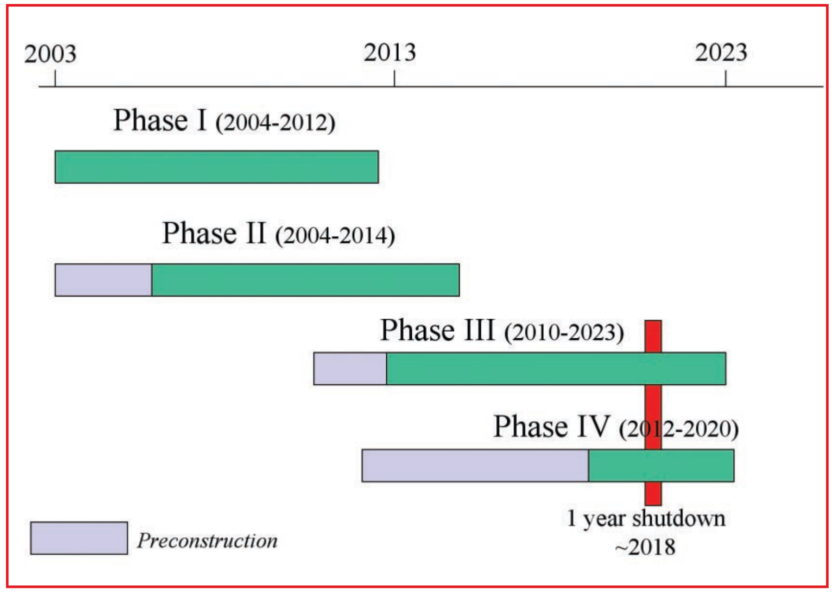



*Fig. A-1. Timeline for implementation of Phases I-IV.*

### *Cost and Schedule:*

We have estimated that Phase III costs will total $400M. (Schedule information and budget profiles can be found in figures A-1 and A-2, respectively.) Conventional facilities upgrades estimated at $45M (for increased cooling capacity, additional office/lab space, etc.) have also been included as a part of Phase III in the $400M request.

## Phase IV- Super Storage Ring

### *Proposal and the Importance of the Science It Would Support:*

Phase IV represents significant changes in all the accelerator systems and can be broken down into two separate parts: the storage ring upgrade and accompanying injector replacement. As stated earlier, given the existing (40-fold) symmetry of the storage ring, only incremental improvements in particle beam brilliance can be expected in the years ahead. This proposal calls for a radical change in the storage ring magnetic lattice to go from a 40-fold symmetry to 80 fold and thereby reduce the beam emittance by 23 or almost a factor of 10. This additional factor of nearly ten in beam brilliance on top of

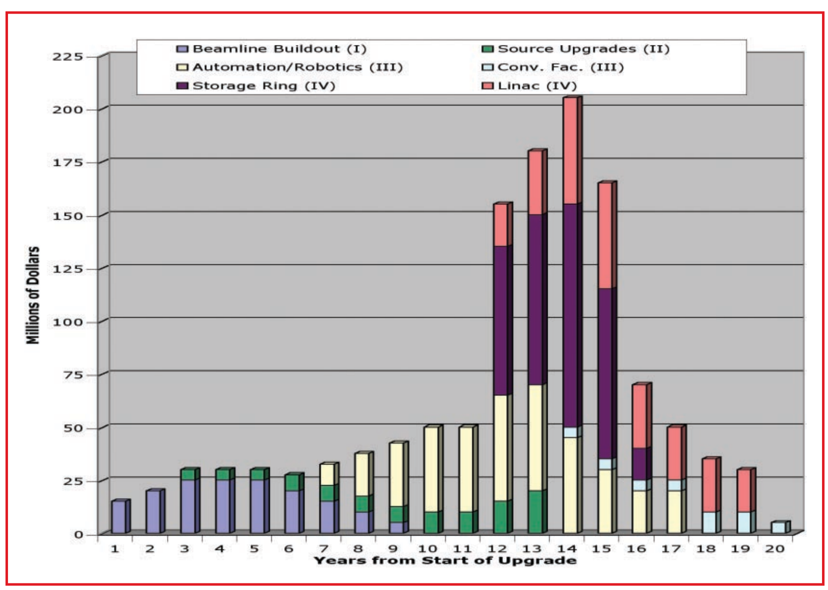



*Fig. A-2. Budget profile for Phases I-IV.*

increased brilliance through optimized IDs, longer straight sections, and increased current would then put the APS near the limit of brilliance attainable with a storage ring of this dimension and energy. This “super storage ring” would provide a significant impact on all brilliance-related techniques, most notably x-ray photon correlation spectroscopy, coherent imaging, inelastic scattering, and x-ray nanoprobe microscopes, all of which have been described above as high-impact techniques. The obvious advantage of this approach is the use of the existing beamlines for this super storage ring.

A considerable decrease in the stored beam lifetime is expected with this new configuration. We estimate that the lifetime would also be at least an order of magnitude lower, *i.e.*, a lifetime of only 30 minutes for a fill pattern of 23 bunches (one of the present operating modes at the APS). To provide top-up mode for this fill pattern (or similar ones) will require a new injector. We propose to build a full-energy linac to replace the existing linac/synchrotron injector system. The proposed full-energy linac would have to be a superconducting linac to provide the repetition rate necessary to maintain a constant current in top-up mode with such short lifetimes. In addition the linac would be designed to have a very low emittance to reduce injection losses. The installation of a 7-GeV SC linac would also allow two additional possibilities: (1) it would free up the existing linac and booster synchrotron for other areas of research (the linac could feed a VUV FEL and the booster could be reconfigured for a VUV source), and (2) with the addition of a secondary SC linac of 3 GeV, beams of electrons ranging in energy from 4 GeV to 10 GeV could be the driver for a soft x-ray FEL and/or a source of short pulses of x-rays (a la the SPPS – the subpicosecond photon source being developed at SLAC). This would provide a source of subpicosecond radiation over an energy range from sub-keV to hundreds of keV. Although not of the instantaneous power level of a true x-ray FEL, it would provide a very exciting source for time-resolved experiments.

#### *Readiness:*

In approximately 15 years, this concept would provide a major upgrade path for the APS. However the actual directions taken will be determined in large part by the direction on the national scene of ERL and FEL development. In principle, the SC linac injector could be connected to a green-field x-ray FEL.

#### *Cost and Schedule:*

We have estimated that Phase IV costs, a 7 GeV SC linac injector and storage ring lattice modification, will total $600M. (Schedule information and budget profiles can be found in Appendices A and B, respectively.) Costs for the conversion of the APS booster to a storage ring and the secondary linac are not included in the $600M cost estimate provided here.

### Center for X-ray Science and Technology

The motivation for the development of a Center for X-ray Science and Technology is built on the facility expertise that exists at the APS and will expand to include theoretical support, development of optics and detectors, and educational outreach that will benefit the entire synchrotron radiation community. The formation of a theory institute closely involved with the science done at the APS will unquestionably increase the productivity and the impact of the entire facility. Theory groups would be established along broad subjects, such as condensed-matter/materials science, chemistry, biology, environmental/earth sciences, etc. These groups would then interact with each other along technique-specific fields such as inelastic scattering, imaging, diffraction, spectroscopy, etc. A close synergy between a theory group and the Center for Nanoscale Materials will only enhance the overall productivity of both Centers.

Theoretical support is already lagging the experimental data generated at the APS, and hence the Center needs to be initiated as soon as possible. It could be nucleated with the hiring of several theorists and then expand as required over the next 15 to 20 years. The Center would also be the focal point for technical advances, such as remote access and automation, adaptive optics and feedback, data analysis programs, detector development, etc. Training and education will also be a cornerstone of the Center. It is essential to ensure that future APS resident beamline scientists are of the highest quality, as these scientists are often critical links between the users, and the success or failure of an experiment relies on these links. Together with the Intense Pulsed Neutron Source (IPNS) staff we have already established a highly successful national summer school at ANL to train graduate students in the capabilities and use of synchrotron radiation and neutron facilities. However this type of training is not adequate and must be expanded. By establishing full-semester courses directly related to the applications of synchrotron radiation to all fields of science, the APS will complement students' formal education from academic institutions with hands-on experience with state-of-the-art beamlines and techniques. We would work with the University of Chicago and/or other regional institutions to provide undergraduate or graduate credit for these courses (similar to what the U.S. Particle Accelerator School does). Furthermore, the educational arm of the Center will have programs for high school teachers and students to provide them with the unique opportunity to work at the premier synchrotron radiation facility in the United States.

Funding for the Center would come to the APS through increases in the operating budget and would require approximately a 5% increase over the existing levels to staff the Center.

## Summary

We are proposing an upgrade path for the APS over the next twenty years in four separate but linked phases. Our aim is for a 102 to 103 increase in brilliance twenty years from now. These enhancements would maintain the APS as a state-of-the-art facility and the premier 3rd-generation x-ray storage ring over this entire time frame. The total proposed investment is on the order of $1B over a twenty-year period, comparable to the depreciation cost of the facility. It bridges the gap between today's 3rd-generation sources and the proposed 4th-generation sources, while continuing to provide the growing user community with a cutting-edge source to meet their increasingly demanding needs to continue to produce science that is second to none.

# Appendix B:

# Participation of General Users at the Advanced Photon Source

# Participation of General Users at the Advanced Photon Source

### Issued: October 8, 2002
### Revised: September 4, 2003

## 1. Objective

The objective of the Advanced Photon Source (APS) general-user program (previously known as the independent-investigator program) is to provide maximum opportunities for productive use of the APS by qualified researchers through a central APS process for proposal submission, peer review, and beam time allocation.

## 2. Definitions

**Beamline:** All instrumentation and facilities that extend from the source in the storage ring to an experiment station.

**Beam Time Allocation Committees (BACs):** Committees that determine which beamline will host each general user proposal and how much time each proposal will receive.

**Beam-time request form:** Form (specific to certain program proposals used to request additional beam time after the initial allocation has been used.

**General user:** An investigator who applies for beam time through the APS peer-review proposal process for general users. The intellectual basis of the research must originate with the general user.

**General-user beam time:** Time made available to general users on an APS experiment station/beamline. All general user beam time is allocated through the APS general user proposal process.

**Primary reviewer:** Member of a Proposal Review Panel who is assigned to lead the discussion of a given proposal.

**Proposal:** General users may submit any of the following three types of proposals:

**Individual proposal:** A proposal for a single experiment.

**Program proposal:** A proposal for an experimental program that may require a series of visits to the APS over a two-year period (less than 10% annually of user time on a given beamline).

**Rapid-access proposal:** A proposal that requests unallocated general user time during the current run.

**Proposal spokesperson:** Person identified on the proposal submission form as primary point of contact.

**Proposal Review Panels (PRPs):** Peer-review groups, organized by technique or scientific discipline, that evaluate the scientific merit and technical feasibility of proposals and provide a rating for each.

## 3. Policy for General-User Access

### 3.1 Determination of Beam Time Available to General Users

All time designated as general-user time must be provided through the APS general-user proposal submission and tracking system.

Each collaborative access team (CAT) or beamline must make at least 25% of its beam time available to general users. Typically, this time is figured as 25% of the number of user shifts scheduled by the APS each year. CATs that operate both bending-magnet beamlines and insertion-device beamlines must provide a minimum of 25% on each beamline. If two or more stations can be operated simultaneously, 25% of the time on each must be provided to general users. Individual CATs or beamlines, by agreement with the APS, may provide a larger percentage of time to general users. CATs may also reserve a portion of beam time for rapid access by general users, with the percentage of time being agreed upon by the CAT and the appropriate BAC.

Several CATs operate as national user facilities; that is, approximately 100% of the beam time is available to general users. All proposals for experiments at these CATs are submitted and reviewed through the APS general user proposal system. However, these CATs award about 75% of the available beam time directly; the remaining proposals are allocated time by the BAC in the usual manner.

Beamlines operated entirely by the APS will make 80% of their beam time available to general users. Facility staff may compete for this general-user beam time through the general-user proposal process. If APS provides partial operational support for a beamline, the amount of general-user time on that beamline will be negotiated on a case-by-case basis.

The APS permits general users to conduct both proprietary and non-proprietary research at the facility. Individual CATs, however, may petition the Associate Laboratory Director for the APS (ALD/APS) to exclude propriety research by general users.

CAT members may apply for general-user time on any beamline. On their own beamlines, however, the following conditions apply:

The CAT formally offers more than 25% of the scheduled user shifts to general users on a regular basis. (CAT members are eligible only for the portion of general-user beam time in excess of 25%.)

The intellectual basis of the research originates with the CAT member applying for general-user time.

### 3.2 Proposal Submission

In general, proposals are solicited three times a year, about two months before each run. Approved proposals are usually scheduled for the next run. General users can submit three types of proposals, which follow somewhat different review processes.

An individual proposal describes a single experiment. Proposals submitted for a particular run are evaluated as a group. Once accepted, a proposal is eligible for scheduling for up to one year from the beginning of the first requested run. If it is not scheduled within that time, the proposal must be resubmitted.

A program proposal describes an experimental program that may require a series of visits to the APS over an extended period (less than 10% annually of user time on a given beamline). Beam time may be allocated in stages or once for the full duration of the program. If time is allocated in stages, after the first visit the investigator must submit a beam time request form for each subsequent visit. Beam time requests forms are submitted and reviewed in the same way as initial proposals. Program proposals are valid for two years from the beginning of the first requested run.

A rapid-access proposal requests immediate use of unallocated general-user time at a specific CAT. Evaluation and scheduling are handled by the selected CAT, subject to retrospective review and general oversight by the BAC.

The APS web-based proposal submission and tracking system is used throughout the proposal process, from proposal preparation to beam time allocation. The prospective investigator uses the web forms to provide detailed information on the experiment (including the specific beamline required, as appropriate) and the research personnel. The system provides access to individual CAT web pages and to a listing of the techniques and equipment available to general users at each beamline.

### 3.3 Proposal Review

Peer reviewers evaluate the scientific merit and technical feasibility of each proposal and assign it a numerical rating. The ratings are defined in Table 1. Reviewers are strongly encouraged to provide comments as well. Different review processes are used for macromolecular crystallography, all other science, and rapid access proposals.

In parallel with the scientific peer review, the APS User Office performs an administrative review of each proposal to ensure that all investigators listed are registered as APS users and that all required user agreements are in place.

### 3.3.1 Macromolecular Crystallography

Each macromolecular crystallography proposal is evaluated independently by two reviewers. These reviewers are drawn from a pool of individuals identified by the user community. The APS User Office maintains a database of these reviewers and assigns proposals on a rotating basis.

### 3.3.2 All Other Science

In all other areas, proposal review is handled by Proposal Review Panels (PRPs). Panels may be constituted in several technical or scientific areas to meet the requirements for competent scientific review of all general user proposals. If necessary, ad hoc reviews may supplement the review provided by a particular panel.

Each panel consists of at least four persons appointed by the ALD/APS for two-year terms, renewable by mutual consent. The ALD/APS also appoints the Review Panel Chairs. The APS User Organization Steering Committee (APSUO) and CAT Directors provide candidates for consideration by the ALD/APS.

Each PRP meets once before each user run. The Review Panel Chair assigns a primary reviewer for each proposal, who must read the assigned proposal and be prepared to lead discussion regarding its content. All reviewers are expected to be somewhat familiar with all proposals and are expected to contribute to discussions of the proposal. At the meeting, the panel reaches a consensus evaluation of each proposal under consideration and assigns a score. Review criteria are available on the APS general user web page.

*Table 1. Definition of ratings used in reviewing general-user proposals*

**1 — Extraordinary** The proposal involves highly innovative research of great scientific importance. Proposed research will significantly advance knowledge in a specific field or scientific discipline. Considerable societal relevance is demonstrated. The radiation characteristics of the APS are highly desirable for the success of the proposed work.

**2 — Excellent** The proposed research is of high quality and has potential for making an important contribution to a specific field or scientific discipline. The work is cutting edge and is likely to be published in a leading scientific journal. The radiation characteristics of the APS are important to the success of the proposed work.

**3 — Good** The proposed research is near cutting-edge and likely to produce publishable results. Impact on a specific field or scientific discipline is likely. Synchrotron radiation is essential to accomplish the intended goals of the research. The proposed work will greatly benefit from access to the APS.

**4 — Fair** The proposed research is interesting but may not significantly impact a specific field or scientific discipline. Publication may or may not result from this research. Synchrotron radiation is required, but the proposed work could be performed at other facilities.

**5 — Poor** The proposed research is not well planned or is not feasible. Results would not make important contributions to fundamental or applied understanding, and work is not likely to result in publication. The need for synchrotron radiation is not clear.

## 3.4 Beamline Evaluation

Each CAT or beamline identified as a potential host for a general-user proposal will determine the suitability of its facilities for the proposed experiment. Each prospective CAT may also provide any other information that may have bearing on the decision on whether to award beam time. This input may include (but is not limited to) environment, safety, and health issues; the past performance of an investigator; specific outreach on the part of the CAT; or a unique suitability of the CAT facilities to accommodate the general-user proposal.

## 3.5 Beam-Time Awards

The reviewers' rankings and comments, and comments from the CATs, are provided to a Beam Time Allocation Committee. Currently, there are two BACs, one for macromolecular crystallography and one for all other science. Members of the BACs are appointed by the ALD/APS for a term of two years, renewable by mutual consent. The Directors of all operational CATs provide candidates for consideration by the ALD/APS. The APSUO Steering Committee appoints the Chairs of the BACs.

The BACs meet once before each user run to determine which proposals will receive beam time and where. However, the allocation process differs for proposals that request a national user facility as a first choice and for those that request rapid access.

The number of shifts (both allocated and rapid access) each CAT is obligated to provide to general users for each scheduling period is determined in advance of the BAC meetings according to the current agreement between the APS and sector management.

### *3.5.1 General Process*

In awarding beam time, the BAC takes into consideration the following factors:

- Proposal reviews and ratings from PRPs.
- Beamline feasibility evaluations.
- Special considerations (in support of outreach goals or for exploratory work).
- Requested CAT(s).
- Likelihood of success.
- Demonstrated need for APS and CAT facilities.

The BAC determines which proposals will be allocated time, which beamline will receive each proposal, and the amount of time to be allocated to each proposal. If only one beamline is requested, the BAC must honor that request if at all possible. The BAC seeks a balance between adventurous, exploratory experiments and those with a clear expected result.

The BAC will also provide a waiting list of approved proposals, by beamline, so that if time becomes available (for example, through the cancellation of an awarded proposal), the next suitable proposal can be accommodated. If no suitable proposals are available, the CAT will be considered to have met its general user obligation for that cycle. Proposals on the waiting list are reconsidered in later review cycles.

### *3.5.2 Special Cases*

For program proposals, the BAC will decide whether to allocate beam time for the whole series of visits (full approval and award) or to require the submission of a beam time request form for each subsequent visit. If the BAC has approved the full series of visits but the CAT believes the time is not being spent productively, the CAT can appeal the full approval to the BAC.

For rapid-access proposals, the requested CAT evaluates the proposal immediately, in parallel with the normal peer review. If the CAT considers the proposed experiment acceptable, beam time can be scheduled. However, the proposal will continue through the normal review process, with the conclusions evaluated retrospectively. The BAC provides oversight of the rapid-access general user proposal process.

For proposals requesting a CAT that is classified as a national user facility, in general, 75% of the beam time is allocated directly by the CAT, from among the general user proposals requesting that CAT. The DOE-required 25% of the beam time is allocated by the BAC through the normal review process. The BAC considers only those proposals that the CAT has not already selected.

If issues arise for which no formal policy exists, the BAC will resolve these issues until a formal policy can be developed and approved.

## 4. Procedures

The proposal submission, review, and allocation system is diagrammed in Fig. B-1 and described in the following sections.

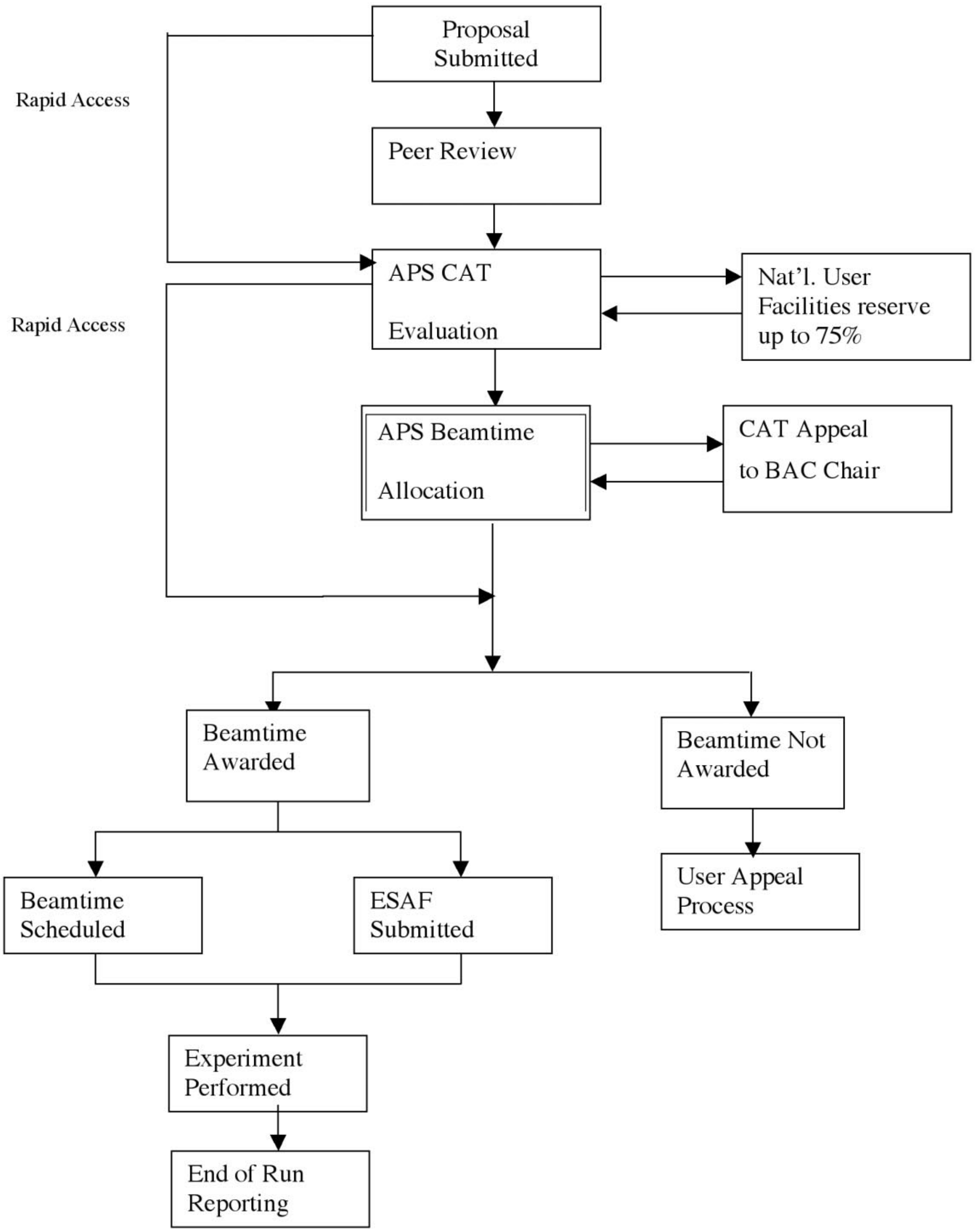



*Fig. B-1. Submission, review, and allocation process for APS general-user proposals.*

### 4.1 Submission

Proposers can request up to three specific beamlines, or they may indicate that any appropriate beamline is acceptable. For proposals in areas other than macromolecular crystallography, at least one CAT must be identified as a potential host. The proposal submission form includes a listing of techniques and capabilities, and the system provides links to individual CAT web pages and the APS Beamline Directory.

A single proposal form is used for all general user experiments. This form requests basic information required by the APS about the proposers, the subject of the proposed research, agencies funding the research, beamline(s) of interest, and an abstract. After the basic form has been completed, the proposer chooses one of two options, Macromolecular Crystallography or All Other Science, and completes a different web form, depending on the choice.

All submitted proposals go simultaneously to the requested CATs, the Proposal Review Panels, and the APS User Office. The User Office checks that all individuals listed on the proposal are registered as APS users and are affiliated with institutions that have valid user agreements with the APS. If some individuals do not meet these requirements, the User Office will immediately initiate the necessary processes. These administrative processes occur in parallel with the review process.

## 4.2 Review

### *4.2.1 Macromolecular Crystallography*

Each macromolecular crystallography proposal goes directly to two reviewers selected by the APS User Office on a rotating basis from an approved pool of reviewers. Proposals are sent electronically to reviewers on Mondays and Thursdays. Reviewers are asked to return their reviews electronically within one week (by the next Monday or Thursday, respectively). If a particular review is not received by that deadline, the proposal is sent to another reviewer. If the scores received differ by more than 2, the proposal is sent to a third reviewer. For each evaluation cycle, the APS User Office uses the review scores to produce a ranked list, which is provided to the appropriate BAC.

### *4.2.2 All Other Science*

The user identifies an appropriate Proposal Review Panel (PRP) on the proposal submission form. For each proposal, the Review Panel Chair determines that the proposal is, in fact, appropriate for the panel and assigns a primary reviewer. For each evaluation cycle, all PRPs meet at the APS within the week following the submission deadline. Working from the definitions given in Table 1, each PRP establishes a consensus score (to two significant digits) for each proposal assigned to it. The PRP also sets a maximum amount of beam time that each proposal should be allocated during its lifetime. This limit serves as a guide to the BAC when beam time awards are made. The User Office uses the consensus scores to produce a ranked list, which is provided to the appropriate BAC.

### *4.2.3 Rapid Access*

Submitted proposals requesting rapid access are considered on a continuing basis and are not subject to evaluation cycle deadlines. To permit timely access, the proposal is sent to the requested CAT at the same time it is sent to the reviewers. The CAT may choose to award beam time and schedule the user's visit before the review is completed. If so, the normal review process will still take place, with the conclusions evaluated retrospectively. The CAT provides a list of scheduled rapid-access proposals to the BAC (through the User Office).

If the CAT declines to award rapid-access beam time to a proposal, the CAT notifies the user. The proposal then reverts to the usual review process and is considered by the BAC in the next review cycle.

## 4.3 Beamline Evaluation

All prospective CATs listed on the proposal are notified when the APS User Office receives a proposal (or beam time request). The CATs may view and comment on the proposal at any time after it is submitted. These CATs also receive the reviewers' reports.

Each CAT has the opportunity to provide input to the BAC regarding the suitability of its facilities for the experiments proposed for its beamline.

Prior to the meeting of the BAC, the CATs designated as national user facilities award beam time to proposals and beam time requests and forward their decisions to the APS User Office for use by the BAC.

## 4.4 Beam-Time Awards

Shortly after the all review scores have been determined and CATs have provided input, the two BACs (macromolecular crystallography and all other science) meet to allocate beam time.

For program proposals in which all visits were not approved initially, the BAC will also review and award beam time based on subsequent beam time request forms (through the same process as for regular proposals).

Immediately following the BAC meeting (and before the general users are notified), the CATs are notified by the APS User Office of the beam time awards on their facilities. Should the CAT strongly disagree with the decision of the BAC (*e.g.*, if the proposed experiment is not technically feasible on the CAT beamline), the CAT Director may appeal to the chair of the BAC. This appeal must be made within two working days. In these cases, the BAC Chair is authorized to act on behalf of the BAC to resolve the CAT appeal.

Once the BAC awards beam time, the CAT is responsible for scheduling the general user experiment and informing the APS User Office of the dates. CATs should make every effort to schedule awarded general user proposals in the next run. However, if no suitable time can be agreed upon with the general user, the CAT may schedule a general user in the following run. Upon mutual agreement between the CAT and the general user, awarded time may be scheduled at a later time.

For rapid-access proposals, a CAT may choose to award beam time at any time after the proposal is submitted. This provides a mechanism for CATs to meet user needs for prompt access to their facilities.

### 4.5 Appeals

If a proposal is not awarded beam time, the APS User Office will notify the proposal spokesperson and explain why. The proposer may modify and resubmit the proposal or withdraw it. If the proposer has concerns about how the review process was administered, he or she may communicate these concerns in writing to the ALD/APS.

Appeals for denial of beam time for a CAT that is designated as a national user facility are heard jointly by the CAT and the BAC. Otherwise, the following appeals are heard by the appropriate BAC:

- Denial of beam time for all CATs except those designated as national user facilities.
- Damage to CAT-owned equipment.
- CAT failure to perform/comply.
- User failure to perform/comply.
- CAT requests to reduce general user beam time obligations.
- CAT appeal of full approval and award of beam time for program proposals.

## 5. APS Responsibilities

The APS provides the following support to the general user proposal process:

- Maintains a web-based system for proposal submission, tracking, and review.
- Maintains a beamline directory listing techniques and equipment available to general users.
- Maintains databases of reviewers and review panels.
- Arranges for peer review of proposals.
- Provides all administrative support for review meetings.
- Notifies users whose proposals have been declined.

## 6. CAT Responsibilities and Rights

### 6.1 CAT Responsibilities

When a CAT is declared operational, it must provide the APS with a memo stating the instruments and techniques that will be available to general users and identifying any exceptions to this APS general user policy (*e.g.*, the exclusion of general users conducting proprietary or classified research.)

Any beamline made available to a general user will be equipped, and in proper working condition, to deliver photons having the radiation characteristics required for the generic class of experiments for which the CAT was approved. The CAT will also supply all equipment that was designated as available to general users when the CAT was declared operational.

The CAT will also permit the general user to use existing CAT laboratory facilities in the Laboratory Office Module for tasks that cannot reasonably be done off-site.

The host CAT will provide each general user with the technical training required to use the beamline and any ancillary equipment to which the general user has been granted access. If a general user requests the use of individually owned equipment not officially designated for general user use, the CAT may refuse the request or, at its discretion, require the general user to use it in collaboration with a CAT member.

During scheduled general user access periods, the host CAT will give general users the same level of technical support that it provides to its members.

### 6.2 CAT Rights

For general user proposals in which CAT members are not collaborating, the CAT may determine that costs associated with the proposed experiment are in excess of routine expenditures. In these cases, the CAT will advise the APS User Office, which will ensure that the general user has a funded operating cost code (User Account) in place to cover the supplies, materials, or services required by the general user. To cover routine costs incurred by general users at the APS, the APS will provide a cost code and spending authority limits.

CATs may request in writing to the BAC that a specific general user not be granted time on its beamlines. The written request must state the reasons for the exclusion of a particular general user. Appeals to the decision of the BAC to these requests will be decided by the ALD/APS. Requests for other exclusions to this policy (*e.g.*, to exclude a particular category of general users) must also be made in writing to the ALD/APS, who will address each request individually.

## 7. General-User Responsibilities and Rights

### 7.1 General-User Responsibilities

All general users must complete appropriate training (at a minimum, APS 101, General Employee Radiation Training, and sector-specific training) and have a valid User Agreement in place between the APS and the institution that sponsors the research. General users who damage CAT-owned equipment after receiving appropriate training in its use will be held liable for the damage, according to the provisions of their institutional user agreements.

Each general user must also submit an Experiment Safety Approval Form for each experiment to be conducted.

General users are required to submit copies (or full citations) of all publications resulting from their work to the APS User Office for inclusion in the APS publications database and to provide copies to the host CAT. In addition, each general user is expected to submit a brief abstract of the work to the APS for inclusion the APS User Activity Report, unless the work has been conducted in a proprietary mode. Failure to submit the required publication citations and abstracts may result in denial of requests for beam time in subsequent proposals. When work performed at the APS by a general user is submitted for publication, the author must include appropriate acknowledgment of the APS and the CAT in the manuscript.

### 7.2 General-User Rights

General users have the right to appeal denial of beam time as outlined under the Appeals section of these procedures.

# Appendix C:

# Policy for Access to the Advanced Photon Source by Partner Users

# Policy for Access to the Advanced Photon Source by Partner Users

Potential users can access the APS either as Partner or General Users. This policy defines Partner Users (PUs) and outlines the access requirements. The detailed process for becoming a PU is defined in the accompanying procedures. The specific requirements and process for General User access are described in the policy entitled "Participation of General Users at the APS" (Appendix B of this document).

## Partner Users:

A PU (individual or group) contributes to the facility or user community beyond simply performing good scientific research, as is typically the objective of a General User. For example, a PU might expect to accomplish one or more of the following:

- Develop a new capability or new instrumentation;
- Develop a dedicated station or beamline;
- Design, build, and operate a full sector;
- Build a new user community;
- Engage in education/outreach; or
- Perform other activities outside the scope of the APS General User program and deemed by the APS Scientific Advisory Committee (SAC) to be valuable to the APS user community.

Typically, a PU requires access to more than 10% of the beam time on a beamline or sector for two years or more.

The time available for general users on any sector must never be less than 25%, leaving the balance for PUs, maintenance, etc. For a sector where APS is the primary operator, then at least 50% of the time will be available to General Users, with an additional 20% reserved for maintenance and operations, leaving a maximum of 30% for PUs.

## Requirements:

To become a PU, an individual or group must, at a minimum, complete the following:

Submit a Letter of Intent (LOI) or short proposal describing the proposed partnership.

Obtain approval of the LOI or short proposal and meet any additional requirements.

The scope of the proposed partnership agreement may necessitate additional requirements, such as the submission and approval of a full scientific proposal, conceptual design report (CDR), management plan, safety plan, and funding commitments. Once a partnership has been established, the PU will operate under mutually agreed upon terms.

A collaborative access team is a special type of PU arrangement as described below in "Definitions."

## Reviews:

The following criteria will be used for evaluation of partnership LOIs and proposals:

- Scientific merit
- Technical feasibility
- Capability of the experimental group
- Availability of the required resources

Note: The above criteria are the same as for General User proposals. The following additional criterion, however, applies to PU proposals:

- Positive impact of partnership on other General Users

Once approved, all PUs will be subject to periodic performance review by the SAC. The criteria for these reviews are spelled out in the policy entitled APS Scientific Advisory Committee Policy. As part of each sector review by a Sector Review Panel (see Guidelines for Reviews by the APS Sector Review Panels), every PU with an active proposal involving that sector will also be reviewed. PU performance may also be reviewed at other times, at the discretion of the APS and the SAC.

### Definitions:

**APS X-ray Operations and Research Section of the APS Experimental Facilities Division:** Facility beamlines are operated by XOR staff members.

**Collaborative Access Team (CAT):** A CAT is a special type of Partner User arrangement. In this model, typically several individuals or institutions join to form the CAT, which is considered in the context of this policy as a single Partner User. A CAT assume full responsibility for design, funding, construction, and operation of a sector. A CAT is allocated no more than 75% of the beam time and must support General Users for the remaining 25% of the operating beam time.

**Collaborative Development Team (CDT):** A CDT is a special type of Partner User arrangement. In this model, typically several individuals or institutions join to form the CDT, which is considered in the context of this policy as a single Partner User. A CDT assumes full responsibility for design and construction of a sector or beamline, and the APS provides at least partial funding. During these phases of sector/beamline development, the CDT members have full use of all beam time, and an executive advisory board oversees activities during this period. As the transition is made to the operational phase, the CDT members receive progressively less beam time as more time is given to General Users, according to a negotiated schedule. After 2-3 years of operation, the CDT sectors/beamlines operate as standard XOR beamlines/sectors. At that time, the APS assumes full responsibility for the operation and funding of the sector/beamline and 80% of the beam time will be allocated to General Users. The executive advisory board serves in an oversight capacity throughout the operational phase.

*5/1/2003*

# Appendix D:

# Advanced Photon Source Scientific Advisory Committee Policy

# Advanced Photon Source Scientific Advisory Committee Policy

The Scientific Advisory Committee (SAC) inherits and expands the role of the former Program Evaluation Board (PEB). It advises the Associate Laboratory Director for the APS (ALD/APS) with the following responsibilities:

## Scope

To evaluate the scientific output and facility utilization for all APS sectors.

To examine performance and recommend appropriate beamtime allocation for existing Collaborative Access Teams (CATs).

To evaluate Letters of Intent and scientific proposals for new and reconstituted CATs.

To provide advice to and review decisions by APS management on special operations support for CATs.

To review Special Program proposals, a new mode of access that will guarantee 10-30% the beam time per year on any sector for a finite period of time.

To assist the APS with development of policies and other issues as appropriate.

## Membership

A 16-member board, constituted as follows:

- Fourteen members, serving staggered two-year terms (renewable by mutual consent)
- APSUO Chair, *ex officio*
- Partner User Council Chair, *ex officio*

The ALD/APS will appoint the members of the SAC. The SAC Chair, selected by the ALD/APS director from the fourteen regular members, will serve a two-year term as Chair and agree to remain on the SAC for the following two years to provide continuity. The term of the chair can be renewed by mutual consent.

## Evaluation Criteria

The following criteria will be used to evaluate the performance of each sector:

### Scientific and Technical Output

The impact of the scientific and technical work being carried out or proposed at the sector.

### Accessibility

The degree to which the sector has attracted or will attract outside users, *i.e.*, non-CAT members, and the support provided for these users. The quality of facilities that are available to outside users.

### Utilization of Beamtime

The effectiveness of use for the CAT's allocated beamtime.

The maturity of the CAT will be considered in all evaluations. In addition, CAT management and operations will be examined if they contribute to problem areas identified by the SAC.

### Process

In general, the SAC will have only one full annual meeting. However, if needed, the SAC Chair and the APS/ALD can call special meetings of the full SAC. A very important part of the SAC charter is review of sector performance. At the annual meeting the SAC will hear reports from stand-alone reviews held by Sector Review Panels (SRP). Each sector has an SRP, and a SAC member chairs each SRP. The SRPs will report their findings to the SAC at the annual SAC Meeting through the SRP chairs. Typically no more than 10 such reviews will be conducted annually. In this way, the SAC can review groups of related CATs before making final recommendations on actions.

The SAC will also review the performance of the APS-operated sectors, *i.e.* those where APS staff members are designated as Operations Managers, in the same manner as it reviews CAT-operated sectors.

All regular SAC business, including oversight of the sector review results and action recommendations, will be carried out at the annual meeting. All 14 members of the SAC are expected to attend this 2-3 day meeting, which will be held in January or February. Between meetings, business may be carried out by e-mail or teleconferencing. Each SAC member will be committed to at least two meetings at the APS per year—one or more SRP meetings and the annual meeting of the entire SAC.

In addition to the regular three-year sector reviews, the SAC will organize at least one stand-alone "cross-cut" review per year on a specific topic (*e.g.* protein crystallography, microscopy, magnetism, etc.) Results from the "cross-cut" reviews will be presented at the annual meeting of the entire SAC and may also lead to recommendations on specific sector actions.

The Construction/Commissioning Review Panel (CCRP) monitors progress of CATs in the construction/commissioning phases of development. The CCRP Chair will report their findings annually to the SAC.

## Sector Review Panels

Performance of each sector will be reviewed on a three-year cycle, with a full day review by a specially selected committee (SRP) chaired by a SAC member. The review will be hosted by the APS. Each SRP will comprise six or more expert reviewers, including at least two specialists in the relevant sciences who are not regular users of synchrotron radiation. Members of the SRPs will be selected by the SRP Chairs and invited to participate by the ALD/APS. A minimum of one SAC member will be a member of each SRP and be responsible for reporting results to the full SAC; however, all SAC members are encouraged to attend sector review meetings. Efforts will be made to cluster relevant sector reviews together and share panel members where appropriate.

Prior to each sector review, a CAT will prepare a document summarizing their prior accomplishments relative to the SAC evaluation criteria, and describing proposed activities for the next review period. The document should be provided in advance to the SRP, and may be sent for external mail review if the SRP Chair feels that the SRP members do not have sufficient expertise. Format instructions for the sector review document will be provided to the Operations Managers of the sectors in advance; it is intended that information about recent successfully reviewed external proposals may be substituted where appropriate. The oral review will consist of scientific presentations, questions from the panel, and visits to the facilities. The panel should prepare its report on the same day.

Midway between the three-year reviews, each CAT will prepare a short written summary of progress for review by the SAC. If the SAC has concerns, it can ask the CAT to come in for a full review as often as once per year.

Addendum I contains the review schedule for 2002 and 2003.

## Assessment of Utilization, Quality, and CAT Time Allocation

It is the policy of the APS that all successfully performing CATs will retain access to 75% of the available sector beamtime, with the remaining 25% allocated to general users. If the APS provides operational support, individual agreements will define the percentage allocations of beam time.

If the SAC concludes that the performance of a CAT on a particular sector inadequately meets one or more of the three criteria above, it can recommend reduced beamtime allocation to the CAT for the next review period. The remaining time will be made available to general users or be accessible to special program proposals. The SAC will give careful consideration before making recommendations to reduce a CAT's beamtime allocation, and will attempt to identify possible corrective actions before taking more severe steps. If a CAT receives less than 75% time on its own sector, CAT members will be permitted to submit competitive general user proposals for time on their CAT's sector, provided the total time allocated to CAT members (either through CAT time or general user allocations) does not exceed a 75% total share.

## Review of Partner User Proposals

Partner user proposals involve applications for more than 10% (but generally not more than 30%) of the time per year on any one sector. This type of access mode has been introduced to permit flexibility in the nature of activities to renew and invigorate the facility. Such proposals could come from any party who would provide resources, including XOR staff acting alone or in collaboration with staff from other CATs.

## Actions to Terminate or Initiate CATs

**Termination:** When the SAC has concerns about the performance of a CAT, it will make written recommendations for remediation. Initial concerns will be reflected in reduced beamtime allocation to under-performing CATs. If subsequent reviews show sufficiently serious problems, the SAC can recommend to APS management that the CAT's sector assignment be terminated. If the APS decides to terminate the CAT's sector assignment, it will inform the CAT in writing of the reasons for its decision. In this event, the CAT's MOU and the CAT member institutions' User Agreements will not be renewed or extended, and the CAT may use the balance of its User Agreement term to phase out its operations, decommission its beamlines, and remove its property from the APS. If a CAT elects to withdraw from the APS on its own initiative, the CAT and the APS will jointly determine the timetable for decommissioning and for removal of the CAT's property from the APS, consistent with sector demand and the impact on general user programs.

**Formation of a new or reconstituted CAT:** Groups that want to form new or reconstituted CATs must have an approved Letter of Intent, approved scientific proposal, approved conceptual design, approved management plan, and a commitment for the necessary funding. The SAC will review the Letters of Intent and scientific proposals. The CCRP will review the conceptual design, and the APS will review the management plan. When all of these requirements have been satisfied, a Memorandum of Understanding (MOU) can be signed with the APS. Sector assignments are made at the time a MOU is signed.

## Role in Overall APS Review Structure

Figure D-1 shows the schematic arrangement of the various APS review boards, but does not include independent review carried out every three years by the Department of Energy.

The University of Chicago Review Committee visits the APS approximately every two years, and reviews the entire performance of the organization for the University of Chicago. The report of this committee goes to the University of Chicago Board of Governors, together with a response from the ANL director.

The Scientific Advisory Committee (SAC) fulfills and expands the role formerly provided by the Program Evaluation Board (PEB). The SAC advises the ALD/APS on the performance of CATs and sectors, on Partner User proposals of limited and intermediate scope, on new proposals for CATs, on other major research activities, and on policy issues.

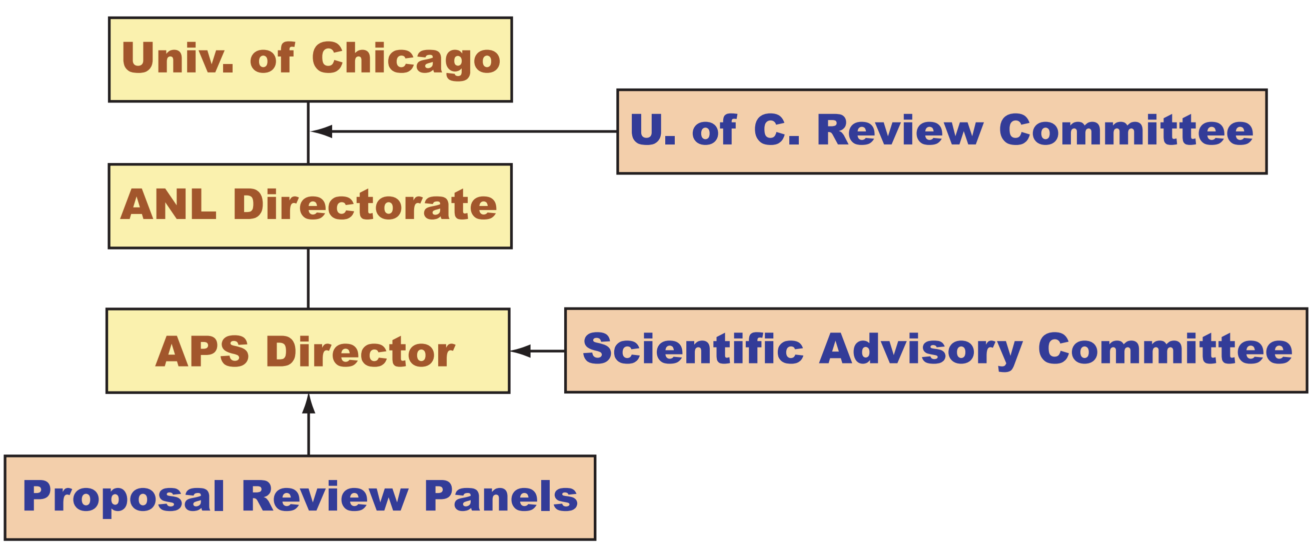



*Fig. D-1. Schematic of APS review boards.*

## ADDENDUM I: CAT/SECTOR REVIEW SCHEDULE FOR 2002-2003

### 2002 (3 CATs/3 SECTORS)

| CAT (Sector) | Review Date |
|---|---|
| CMC (9) | November 19, 2002 |
| DND (5 | November 20, 2002 |
| MU (6) | November 21, 2002 |

### 2003 (8 CATs/7.5 SECTORS)

| | |
|---|---|
| SER (22) | June 2, 2003 |
| BioCARS (14) | June 3, 2003 |
| IMCA (17) | June 4, 2003 |
| SBC (19) | June 5, 2003 |
| MR (10) | September 10, 2003 |
| PNC (20) | September 11, 2003 |
| IMM (8-ID) | November 12, 2003 |
| ChemMatCARS (15) | November 13, 2003 |

# Appendix E:

# Advanced Photon Source Scientific Advisory Committee Members

# Advanced Photon Source Scientific Advisory Committee Members

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Dr. Bertsch's research interests are in the area of molecular environmental science, particularly the biochemical processes that control the cycling and fate of carbon, trace elements, and contaminants with soils, groundwater, and surface water.

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Professor Helliwell is highly involved in the development of crystallographic methods for the study of difficult biological samples through synchrotron radiation. His current research includes structural studies of the saccharide-binding protein concanavalin-A and the carotenoid-binding protein multi-macromolecular complex crustacyanin.

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Dr. Hendrickson studies the structure and biological action of macromolecules, using diffraction analysis and other biochemical and biophysical methods. He and his co-workers combine specific structural studies on important biological problems with methodology development aimed at facilitating these and related investigations.

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Dr. McWhan's research interests are in the areas of phase transitions using x-ray and neutron scattering techniques, including magnetic and time-resolved scattering, as well as in research into the magnetic and electronic properties of new materials.

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Prof. Norris's research focuses on natural and artificial photosynthesis. The goal of the research is a more complete understanding of the beginning of the process of natural photosynthesis such that artificial photosynthesis can be a reality. The mechanism and structural requirements of photosynthesis are explored via a series of photosynthetic reaction centers altered by site-directed mutagenesis.

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